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THE USE OF GYPSUM
IN THE RECLAMATION OF SOLONETZIC SOILS

A THESIS
SUBMITTED TO THE FACULTY OF GRADUATE STUDIES
IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE
OF MASTER OF SCIENCE

DEPARTMENT OF SOIL SCIENCE

BY
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The undersigned certify that they have read,
and recommend to the Faculty of Graduate Studies for
acceptance, a thesis entitled "The Use of Gypsum in the
Reclamation of Solonetzic Soils", submitted by David N.
Graveland, in partial fulfilment of the requirements for
the degree of Master of Science.

ABSTRACT

The object of this study was to determine the value of gypsum as a chemical amendment for the reclamation of solonetzic soils in Alberta. The B horizons of ten solonetzic soils were collected from the Brown, Dark Brown, Thin Black and Black Soil Zones. The exchangeable sodium percentage of these soils varied from 1.4 to 37.3. The soils were leached with solutions of different calcium concentrations. Successive aliquots of the leachates were analyzed for cation and anion concentrations in order to observe the order and magnitude of salt removal and exchange reactions. The soils were subjected to various chemical and physical tests to measure the effect of the amendments on the soils. A greenhouse study was also set up to test the effect of reclamation on plant growth.

The results show that gypsum is an effective corrective for solonetzic soils that are not exceedingly high in exchangeable sodium. This exception is probably due to the limited solubility of gypsum. However, it appears that it can be used for the reclamation of most solonetzic soils in Alberta, particularly those that are rather high in soluble salts and are currently classified as saline-alkali soils. In most soils gypsum was very effective in reducing the exchangeable sodium, but had a lesser effect on the replacement of adsorbed magnesium and practically no effect on adsorbed potassium.

Other effects of gypsum were a slight lowering of the soil pH, a reduction in soluble bicarbonates, and a considerable increase in plant growth. The physical measurements indicate a considerable improvement in soil structure and stability with increased rates of calcium.

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INTRODUCTION

Civilization began in an environment requiring irrigation for agriculture. It has been during the past 1500 years that the scene of greatest agricultural activity has shifted to more humid regions. It is upon these humid lands that the great population centres have grown. With an ever-increasing population, the world is again turning to further development of arid and semi arid lands.

According to Thorne and Peterson (70) the problems that distinguish arid and semi-arid soils from humid soils are salt accumulation, high alkalinity and excessive lime accumulations. The Province of Alberta is not exempt from these problems. Odynsky (55) estimated that there are ten million acres in Alberta where solonetzic soils are either continuous or form not less than 20 per cent of the mixture.

Many problems are encountered in the attempt to develop a satisfactory agriculture on these soils. Their impervious nature tends to delay drainage in the spring and makes seed bed preparation a very difficult operation. All cultural operations are more time and fuel consuming because of the greater density of the subsoil. The germination is usually affected and the final yield is often far below that of normal soils.

Due to the usual patchy nature of solonetzic soils it is often very difficult to exclude them from the field, thus they are treated in much the same way as the more productive associated soil. This is very serious in an irrigated area where an intensive agriculture is a necessity and costs of operation per acre are much higher than in

dry land farming areas.

The poor infiltration rates associated with these soils tend to cause ponding for a considerable length of time after an irrigation. This often leads to a slow salinization of adjacent soils. Lewis et al. (47) by using radioactive tracers found a restricted movement of moisture downward in the surface of slick spots and a fair rate of upward movement which has contributed to a salt accumulation in the surface horizons.

The reclamation of these solonetzic soils presents a variety of problems and a variety of corrective treatments have been attempted. According to Kelley (38) the adsorption of sodium is more important chemically and much more difficult to overcome practically than an excess of soluble salts. Most workers recommend the replacement of the adsorbed sodium by a more suitable cation, usually calcium, and the subsequent removal of the now soluble sodium ion.

This project was initiated to study the effects of the calcium ion on the solonetzic soils of Alberta. Sulfuric acid and elemental sulfur can be used on soil containing sufficient lime to react with the amendments to form a more soluble form of calcium. However, many of the solonetzic soils in Alberta contain insufficient lime in the problem horizons, and also the reaction is often very slow.

The two more soluble calcium compounds utilized in reclamation are CaCl_2 and $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ (gypsum). The high cost of CaCl_2 is prohibitive in most cases. Gypsum, however, although less soluble is much more readily available and less expensive. The fertilizer in-

dustry in Alberta has made available vast quantities of gypsum which has no present market.

It was, therefore, thought desirable to confine this study to the application of gypsum to solonetzic soils and to determine if the solubility limit would be sufficient to meet most requirements in Alberta soils.

LITERATURE REVIEW

CLASSIFICATION OF SALINE AND ALKALI SOILS

Four systems of classification of saline and alkali soils are reported by Thorne and Peterson (70). These include the Hilgard system, the Russian system, the de Sigmond system and the U. S. Regional Salinity Laboratory system.

The U. S. Regional Salinity Laboratory (73) has classified saline and alkali soils as follows:

- (1) Saline soils. This term applies to soils that have a saturation extract with an electrical conductivity of 4 mmhos/cm. or greater, and an exchangeable sodium percentage less than 15. The pH is usually less than 8.5. These soils correspond approximately with de Sigmond's saline soil, Hilgard's white alkali soil and with the Russian's solonchak.
- (2) Saline-alkali soils. This designation refers to soils whose saturation extract has an electrical conductivity of more than 4 mmhos/cm. The exchangeable sodium percentage is greater than 15, and the pH is usually below 8.5. This corresponds closely with de Sigmond's salty alkali soil. The colloids remain flocculated until the salts are leached out, which usually results in a dispersed physical condition and a rapid increase in pH values.
- (3) Nonsaline-alkali soils. This group includes soils having an exchangeable sodium percentage greater than 15. The electrical conductivity of the saturation extract is less than 4 mmhos/cm., and the pH is usually over 8.5. These soils correspond approximately with de Sigmond's leached alkali soils and with the Russian's solonetz soils.

De Sigmond's classification differs only in that he uses saturation of 12 per cent sodium plus potassium as a lower limit.

The Russian system goes a step beyond this classification by defining "solod" or "soloth" soils. These are soils which were formerly solonetzic, but in which the exchangeable sodium has largely been removed and replaced by hydrogen.

The Canadian National Soil Survey Committee (62) has subdivided solonetzic soils on the basis of the degree of development of the A_2 and solonetzic B horizon into Solontez, Solodized Solonetz and Solod soils.

Bentley and Rost (6) described the formation of these three sub-groups. The formation of a solonetz is due to the removal of salts from the solonchak. When the soil exchange complex contains 10 to 15 per cent exchangeable sodium or more, hydrolysis occurs during the salt removal and gives rise to an increase in pH values. The process involved is termed desalinization and alkalization or, collectively solonization. The next process, solodization, occurs when the exchangeable sodium and peptized colloids are removed from the A horizon by eluviation and accumulate in the B horizon. This gives rise to a distinct morphology. The A_2 horizon which develops is platy and vesicular in structure, while the B horizon becomes a dense, compact, highly colloidal and impervious clay pan layer. During dry periods vertical cracks form in this clay pan horizon and a columnar structure develops. Such a soil has been designated as a solodized solonetz. As hydrolysis and leaching continues the A horizon thickens and the B horizon is correspondingly reduced in thickness. The columnar structure of the B horizon becomes less distinct as the columns tend

to break into nut-like fragments. This process continues until the profile loses its solonetzic characteristics and becomes friable to a considerable depth. This soil is now called a solod.

The following nomenclature recommendations have been made by Bower et al. (9): Sodid soil - Use this term instead of alkali soil as defined and used in Handbook 60. (73). Saline soil - Modify the Handbook 60 (73) definition of this term by dropping the restriction that saline soil be nonalkali (i.e. nonsodic).

THE EFFECT OF SODIUM ON PLANT GROWTH

The exact role of sodium in plant nutrition is still a subject of controversy. Whether it assists in the functions of potassium in the metabolic processes of the plant, or whether it has in certain plants, functions that it alone can fulfill, is a question yet to be answered. Harmer et al. (29) felt that the latter was more likely because certain crops that showed marked increases in yield when sodium was applied, also showed a vigor and a state of health not apparent when heavier applications of potassium compounds were supplied in the absence of sodium. They felt that the ability of certain crops to adsorb sodium in large quantities, and to show considerable growth response to it, is an inherited characteristic acquired through long exposure to soils and atmospheres high in sodium content. These authors divided plants into four groups on the basis of their response to sodium, as follows:

- (1) Little or no response even with insufficient potassium supply.
- (2) Slight to medium response with insufficient potassium supply.

(3) Slight to medium response with ample potassium supply.

(4) Large response with ample potassium supply.

Barley is one of the crops considered to be in the second group.

Bower and Pierre (10) suggested that sodium can replace potassium to some extent in the nutrition of some crops. However, Cooper et al. (19) after obtaining slight increases in yield from inclusion of sodium in fertilizers at all rates of potassium suggested that sodium may have some specific functions in the growth of the cotton plant. A reciprocal relationship was found between sodium and calcium in the plant.

Truog et al. (72) found that barley and oats gave an intermediate response to sodium fertilizer, while beets, rutabaga, carrots and celery were highly responsive to this element. However these increases were obtained only when the natural occurring exchangeable sodium of the soils was below 75 pounds to the acre. This apparent increase in response of crops to sodium may be explained by the work of Cope et al. (20) who found that additions of sodium to Mardin silt loam increased the release of nonexchangeable potassium by about 40 per cent.

Pearson and Bernstein (56) stated that sodium shows a stimulating effect up to an exchangeable sodium percentage of 5 per cent. They found that increasing sodium and decreasing calcium and magnesium concentration in the plant material was related to exchangeable sodium percentage rather than to the total amount of exchangeable sodium in the soil. While small amounts of sodium present in the soil may be desirable, excessive amounts were apparently deleterious. Germination tests on wheat, barley, oats, rice, tall fescue and tall

wheat grass by Pearson and Bernstein (56) showed that only oat germination was affected by high exchangeable sodium percentage. Exchangeable sodium percentages in the range of 36-60 tended to cause necrosis and the eventual death of some of the seedlings. Oats was most seriously affected, then barley and then wheat. After establishment the yield of barley was relatively unaffected at exchangeable sodium percentages under 40. In this respect it was much more tolerant than oats or wheat.

Ratner (58) and Chang and Dregne (16) indicated that growth is reduced even when effects of physical conditions were nullified as much as possible. This supports the hypothesis that exchangeable sodium has an effect on plant nutrition. Bernstein and Pearson (7) found that increasing exchangeable sodium percentage resulted in increased sodium accumulation in the tops. Calcium generally decreased but magnesium and potassium may increase or decrease depending upon the crop specificity. They suggested that excessive sodium accumulation by roots may affect their water adsorption function. They noticed that reduction in growth with increasing exchangeable sodium percentage levels was accompanied by an increase in per cent dry weight of plant material. They postulated from this that growth retardation was not caused, initially at least, from inhibition of the assimilatory processes, but possibly by the inhibition of some specific metabolic growth step.

Kelley (38) in an experiment using artificially sodium saturated soils of slightly alkaline reaction with a non-limiting oxygen supply found the soil to be highly toxic to barley. Observations from this experiment showed that the roots that were formed never became more

than a few millimeters in length and were coarse and stubby. He stated that the appearance of the roots suggested a highly toxic condition and that further investigation showed that the soil solution was not toxic. This indicates that the toxic factor was not present in the liquid phase. He suggested that calcium ions, derived from the seed by the seedlings, were exchanged for sodium ions in the soil, resulting in a loss of some calcium by the seedling. Thus the seedlings were not able to obtain calcium from the soil or retain that inherited from the seed. It has been suggested that the same reaction may occur with potassium. The fact that sodic soils which are high in exchangeable sodium are often found to be toxic to germinating seedlings is probably because of this type of reaction.

Chang and Dregne (16) suggested that even on a given soil type there may be no clear cut critical exchangeable sodium level beyond which crop growth will be seriously suppressed. It appears more likely that, in a given soil type, the permissible exchangeable sodium percentage depends upon soil conditions, soil management, and the species and variety of crop. Therefore it is not logical to establish any arbitrarily designed value as the lower sodium limit for sodium soils. Inasmuch as the reduction in yield and the reciprocal relation between sodium and calcium in plants were always related to the degree of sodium saturation in the soil, it appears possible to estimate the sodium status and to predict the critical sodium level through plant tissue analysis.

THE EFFECT OF EXCHANGEABLE CATIONS ON SOIL STRUCTURE

The role of the adsorbed cation in soils has been a subject that has received a great deal of attention for many years. Although general agreement has been reached on the overall effect, a good deal

of work is still being done to tie down the specific effects of closely related cations.

Wiegner, as reviewed by Kelley (38), was one of the first to point out that the degree of dispersion of clay is determined by the adsorbed cation. He showed that the degree of dispersion of clay particles, the surfaces of which are saturated with different cations, follows the Hofmeister ion series. He stated that clays are more strongly hydrated and more dispersed the higher the hydration of the adsorbed cations, and that clays saturated with monovalent cations are more dispersed than those saturated with divalent cations.

Jenny and Reitemeier (34) in their work on the mechanism of ionic exchange in colloidal clays found a definite relationship between ionic exchange and the stability of clay suspensions. They showed that the energy with which an ion was held on the surface of the particle was determined by the effective size of that ion. This energy of adsorption determines the potential of the particle and the stability of the suspension.

Replaceable cations with different degrees of hydration affect the swelling of colloidal clay and govern the formation of soil capillaries. It was the opinion of Menchikosky (50) that the ions most responsible for the physiochemical changes of the soil are calcium and sodium. Wide differences in their degree of hydration (molecules of water to one equivalent of cation, for sodium - 66 and for calcium - 14) have been established according to Menchikosky.

In the process of hydration of colloidal clay in soil, two types of structural transformations are probable according to the above author. First the non-capillary spaces are converted into capillary

tubes, and second the diameter of the original capillary tubes change. He described three phases in the development of soil structure under the influence of replaceable cations:

(1) Cavern-capillary, where the transformation of "soil caverns" to capillary tubes begins. (2) The capillary, when the soil is composed of capillary tubes. (3) Capillary disperse, when the further increase in the amount of replaceable bases as well as in the sodium/calcium ratio results in the beginning of peptization of colloidal clay.

Menchikosky summarized the process in this manner: Starting with a low content of replaceable bases, a slight increase in the sodium/-calcium ratio results in increased capillary rise and downward movement of water. With a high content of replaceable bases and a further increase in the ratio of sodium to calcium a decrease in capillary rise and downward movement will result. As the sodium to calcium ratio increases still further the internal surface increases continuously and a state of severe dispersion and very poor physical structure will result. He suggested, first, that these soil-water properties are produced by the change in number and diameter of equivalent capillary tubes in the soil, and second, that these variations of diameter are due to different degrees of swelling of the soil colloidal clay.

According to Kelley (38) most soils are granular when calcium saturated; their tilth is favorable, save when the clay content is excessive. On the other hand, soils containing excessive exchangeable sodium tend to be dispersed and are relatively impermeable to water; their tilth is quite opposite to that of the same soil when calcium saturated.

Gedroiz, as reviewed by Kelley (38), showed that the amount

of fine particles was greatly increased by saturating the exchange material with sodium. He found that some of the silt and fine sand particles were broken down to much finer dimensions. This did not occur when the soil was calcium saturated. Calcium ions tend to bind the soil particles into aggregates, whereas sodium ions cause dispersion.

As previously mentioned, the increase in the sodium to calcium ratio results in a decrease in the volume of non-capillary spaces. This volume is usually the same as the air capacity. Therefore the increase of exchangeable sodium usually lowers the air capacity of soils.

As discussed by Baver (4) soils made up of granules smaller than 0.5 mm. in size have extremely low air capacity, while those having over 0.5 mm. in size have a large air capacity.

Carroll and McHenry (14) found an appreciable increase in the moisture equivalent for illuviated horizons when the soil was chemically dispersed. This was assumed to be the result of an increase in surface area resulting from the destruction or partial destruction of the aggregates. In sodium saturated soils this increase in moisture equivalent may have been partly caused by the presence of the highly hygroscopic sodium ion.

Reeve et al. (61) in their study of various cation effects upon structure of soils found that for a given soil the crusting tendency increased linearly with increasing exchangeable sodium percentage. In this same study they found that air permeability was not essentially changed with increasing exchangeable sodium, however, the air-water permeability ratio was greatly increased with increasing exchangeable sodium percentage.

The effect of exchangeable sodium on soil structure can be summarized as follows:

Increased exchangeable sodium results in the instability of soil aggregates and gives rise to:

- (1) poor infiltration of water,
- (2) reduced drainage and poor salt removal under irrigation,
- (3) reduced capillary rise,
- (4) reduced air capacity,
- (5) increased moisture equivalent,
- (6) increased crusting tendency,
- (7) increased air-water permeability ratios indicating the poor water stability of the soil aggregates.

De Sigmond's (66) proposal that exchangeable sodium and exchangeable potassium should be considered additive in defining alkali soils has led to further investigations as to the effect of exchangeable potassium. Reeve et al. (61), using the air-water permeability ratio and modulus of rupture measurements, compared the effects of exchangeable sodium and potassium. Exchangeable potassium had little or no effect upon the physical stability of soil structure as measured by air-water permeability ratios, whereas the ratio increased exponentially with increasing exchangeable sodium levels. The ratio increased progressively from one soil to another with increasing cation exchange capacities or specific surface. A linear increase in modulus of rupture for all soils was found with increasing exchangeable sodium percentages, the greater slopes being associated with larger cation exchange capacities. Exchangeable potassium had no effect on modulus

of rupture for soils having a cation exchange capacity of less than about 25 m.e. per 100 grams of soil, but with exchange capacities above this value the modulus of rupture decreased significantly. These data indicated that exchangeable potassium does not have the same unfavorable effect as sodium.

Reports on the occurrence of magnesium solonetz has also prompted investigations on the effect of adsorbed magnesium in soils. Brooks et al. (13) investigated the effects of adsorbed sodium, magnesium, and potassium on soil structure as measured by the air-water permeability ratio and modulus of rupture. A slight increase in the permeability ratio with increasing exchangeable magnesium was found, but this increase was very small when compared with the effect of exchangeable sodium. The effect of adsorbed potassium was more like that of exchangeable magnesium than that of sodium.

The modulus of rupture was only slightly affected by exchangeable magnesium. All the curves for all soils had the same slope when exchangeable magnesium was plotted against modulus of rupture expressed in bars. This indicates that the effect of adsorbed magnesium is similar for all soils. This is not the case with exchangeable sodium as the modulus of rupture increases with increasing cation exchange capacity. The addition of potassium to sodium soils did not affect the physical condition of the soil in any way.

They also measured the amount of organic matter removed by leaching from soils high in exchangeable calcium, magnesium, potassium, and sodium. Their data showed that the relative amounts of organic matter removed were similar for calcium and magnesium saturated soils and were

of higher magnitude when the soil was saturated with potassium and still higher when saturated with sodium.

THE EFFECT OF SOIL STRUCTURE ON PLANT GROWTH

According to Baver (4) soil structure plays an important role in determining water and air relationships within the plant root zone. From a practical point of view, a study of soil structure, particularly with respect to aggregation and porosity, aids in diagnosing and correcting troubles encountered in the growing of plants. Baver goes on to say that the water relationship of the soil depends on the amount and nature of the pores present: the water-holding capacity of the soil depends on the smaller pores, the drainage capacity and aeration on the larger pores.

Meyer and Anderson (52) stated that in general, inadequate aeration results in a retardation in the growth of most plants. Well aerated plants are usually taller and heavier, and have larger and more fibrous root systems. The ash contents are also usually higher. The retarded growth of plants in poorly aerated soils undoubtedly results largely from the reduced absorption of water and minerals which occur under such conditions. The reduced absorption of water appears to be due to an oxygen deficiency rather than the accumulation of carbon dioxide.

However, Chang and Loomis (17) found that very high percentages of carbon dioxide had a marked retarding effect on absorption of water by a number of plants. They also stated that there is strong evidence of a direct toxic effect of carbon dioxide on both plant and animal protein. Hoagland and Broyer (32) explained the absorption re-

tardation as being caused by an initial decrease of permeability of root cells to water.

Findings of Leonard and Pinckard (46) showed that a carbon dioxide content of at least 30 per cent of a gas mixture was necessary to result in even a small inhibiting effect on the growth of cotton roots. Carbon dioxide concentrations above 15 per cent are not often reached in soils, but concentrations of oxygen low enough to affect growth are frequently reached in poorly aerated soils. It has been found that oxygen concentrations below 10 per cent will result in retarded growth according to Meyer and Anderson (52).

Flocker et al. (25) wrote that reduced air space below 30 to 35 per cent retards many metabolic processes related to plant growth and produced a higher water percentage in plant material.

Richards (63) working on soil crusting said that seedlings can be critically influenced by the mechanical condition of the surface soil. Soil crusts formed by wetting and drying after planting often limit the stand of crops. This is particularly true of soils containing excessive amounts of exchangeable sodium.

RECLAMATION OF ALKALI SOILS

Many reclamation studies have been made in the Western United States over the past 50 years with varying results.

Hilgard's (31) early studies of arid lands in California revealed that the unproductivity of "alkali" soils was caused by the accumulation of excess soluble salts and that different kinds of salts produced different degrees of plant injury. Hilgard devoted extensive study to the origin and mode of accumulation of soluble salts in soils

as well as to methods of reclamation.

His theory that sodium carbonate was the characteristic that was responsible for poor growth in alkali soils placed special emphasis on soluble anions of alkali soils. He believed that removing the soluble salts would produce a normal soil. He recognized, however, that the physical properties were extremely adverse after leaching with water. This was attributed to the deflocculation effect of sodium carbonate. He recognized that gypsum had a beneficial effect in most cases. This was attributed to the simple reaction:



Following Hilgard's pioneer work in this field, Kelley and Brown (41) and de Sigmond (65) emphasized the significance of base exchange reactions in alkali reclamation. Based on extensive studies of different kinds of "alkali" soils Kelley (34) pointed out that clay and humus colloids of the soil react with sodium from the sodium salts present, thereby producing a physical condition of the soil which in itself is harmful to crops and which must be overcome before the soil can be truly reclaimed.

Kelley and Thomas (43) stated that the reclamation of soils thus affected requires the application of chemical amendments such as gypsum or sulfur, or combinations of these with manure, followed by heavy leaching.

However not all so-called "alkali soils" require chemical treatment for improvement. Thomas (68) found that certain soils in the Imperial Valley in California were reclaimed sufficiently to produce large crops merely by heavy leaching with Colorado River water. This was verified by Reeve et al. (60) who reclaimed soils in Utah with

four acre feet of water where adequate drainage was available. The soils in this area had a high gypsum content in the surface foot, as well as down through the profile.

In considering leaching as a practical means of reclamation of alkali soils, the economic aspect in addition to the physical factors related to reclamation must be taken into account. These were listed by Reeve et al. (60) as:

- (1) Adequacy of drainage,
- (2) Availability of irrigation water,
- (3) Cost of leaching,
- (4) Cash returns resulting from reclamation.

Kelley and Brown (41) listed some of the factors worthy of examination for the reclamation of alkali soils. These are:

- (1) The concentration and composition of the soluble salts present,
- (2) The replaceable bases,
- (3) The content of easily decomposable calcium compounds,
- (4) The composition of the irrigation water,
- (5) The drainage conditions.

Bower et al. (11) listed the principles of soil reclamation as follows:

- (1) The establishment of drainage if a high water table exists,
- (2) The replacement of sodium by calcium or some other divalent cation,
- (3) The removal of excess salts by leaching,
- (4) The rearrangement and aggregation of soil particles so as to improve soil structure.

The Russians, Antipov-Karataev et al. (1) and Novikova (54)

did not consider irrigation and drainage as being of prime importance. They maintained that reclamation of solonetz and alkali soils can be brought about under semi-arid conditions with the application of amendments and careful moisture conservation without leaching by irrigation or drainage.

Many studies have been conducted on the reclamation of various alkali soils using several soil amendments.

Snyder et al. (67) reported that gypsum was not advantageous in the reclamation of permeable soils. They stated that proper irrigation and adequate drainage is more important in the recovery of permeable soils than the use of gypsum. A broadcast application of gypsum on impervious soils was only slightly better than the check plot which was leached with irrigation water. However, irrigation water treated with gypsum improved soil permeability considerably and had a lasting effect.

Fitts et al. (24) compared the effects of applications of sulfur, CaCl_2 and CaSO_4 on alkali soils and found that all treatments increased water infiltration rates with sulfur being most effective except for a short time at the beginning. Sulfur was also the most effective in decreasing the percentage of large clods, increasing root penetration, reducing pH values and lowering the content of adsorbed sodium in the soil. However all treatments improved the soil for plant growth.

Kelley and Brown (42) found that the plots leached with water did not produce a good yield until after six years of irrigation, while plots leached using gypsum and sulfur gave good yields after a short period of time, also these amendments were much more effective in

reducing exchangeable sodium content. They also found that the exchangeable potassium in the soil was almost entirely replaced by calcium. In another paper, Kelley and Arany (39) reported that gypsum applications only slightly reduced the amount of adsorbed magnesium.

Chang and Dregne (15) while comparing the effect of sulfur, CaCl_2 , sulfuric acid and gypsum on a saline alkali soil found that gypsum was the most effective while CaCl_2 failed to increase yields. This was believed to be caused by the increased salinity status caused by the more soluble calcium compound. Thomas (68) found that gypsum and sulfur were equally effective in alkali reclamation but that in some cases very large applications of gypsum were required. McGeorge et al. (53) observed that gypsum treatments had the following effects: increased sodium in the drainage water; increased capillary rise and percolation of the soil; decreased exchangeable sodium in the soil considerably, exchangeable potassium to a limited extent, and exchangeable magnesium considerably; and lowered the turbidity of the drainage water.

Bower et al. (11) found the beneficial effect of several amendments and combination of amendments were rated in this order: barnyard manure + gypsum, manure + lime, manure, gypsum, sulfur, manure + sulfur, lime.

Mathieu (49) found that sulfur and gypsum treatments increased yields and improved structure on Alberta solonetz soils. However, he stated that the magnitude of the increase fell far short of justifying the expenditure required in applying the amendments. Only under a much more intensive agriculture would such an expenditure be practical. He suggested that an improvement program based on sound

cultural practices inter-related with the application of chemical amendments and good crop rotations would be the most practical and permanent method of reclaiming solodized solonetz soils under irrigation.

The various results obtained from the above mentioned experiments have resulted in more detailed work on the actual mechanism involved in the reclamation of alkali soils.

The effect of moisture content on the soluble salts of saline, gypsiferous and calcareous soils has been studied by Kelley and Brown (40), Hibbard (30), Eaton and Sokoloff (21), Kelley (37), and Vanoni and Conrad (74). In almost all cases the amounts of calcium, magnesium, sodium, potassium, carbonates, bicarbonates, sulfates, phosphates and silicates increased on dilution. Several workers report equal amounts of chlorides and nitrates at different soil water ratios. Eaton and Sokoloff (21), however obtained significant decreases in amount of dissolved chlorides on increasing the moisture content from field moisture content to 500 per cent. This was explained by the concept of "bound water" in which salts would be less soluble than in ordinary water.

The interrelationships of moisture content, dissolved cations and exchangeable cations have been studied by Kelley and Brown (40), Eaton and Sokoloff (21) and Kelley (37). Eaton and Sokoloff (21) found that in three saline calcareous soils the soluble calcium and magnesium decreased on dilution. They postulated that calcium and magnesium entered the exchange complex on dilution and liberated sodium. This process is called the "dilution effect". Kelley (37) presented data which indicated a decrease in dissolved calcium in one soil and a

significant decrease in soluble magnesium in two soils. It was shown that some slick spot soils which contain high proportions of exchangeable sodium at field moisture tend to become saturated with calcium and magnesium on washing with distilled water.

The observation that soluble calcium replaced sodium on the exchange complex upon dilution was expressed in this manner by Gapon (26): "In base exchange involving two cations of equal valency, the equilibrium is not affected by addition of water, but if the cations are of different valency, the cation of lower valence is displaced from the adsorbent to an extent that increases with dilution". Further evidence of the cation dilution effect has been presented by Ivanov and Gapon (33), Kurchatov and Koxlikhin (45), and Magestad et al. (48).

Jenny and Ayres (34) showed that with varying proportions of two cations on the exchange complex the ease of replacement of the more tightly held cation decreases markedly with a decrease in the saturation of that cation. Thus in a calcium-sodium system, a decrease in exchangeable calcium with a corresponding increase in exchangeable sodium would decidedly lower the replacement of the calcium.

Gardner (27) reported that high sodium soils treated with calcium had the same poor physical structure as the original if they were not subjected to proper drying. The calcium treated soils were much improved physically after drying. Similar results were obtained by Falconer and Mattson (22). Gardner also found in greenhouse trials, that although the physical condition of the treated soils was much improved there was no marked increase in yield.

The aim in reclamation of alkali soil is to replace the exchangeable sodium by calcium. The accepted reaction for gypsum

reclamation is: $\text{Na}(\text{soil}) + \text{CaSO}_4 = \text{Ca}(\text{soil}) + \text{Na}_2\text{SO}_4$. This is more efficiently done if the soil permeability can be maintained during reclamation.

Christiansen (18) was of the opinion that the use of water of low electrolyte content would result in soil sealing to such an extent that reclamation would not be possible. Fireman (23) working with Hesperia sandy loam obtained a high and constant permeability when 800 ppm. CaCl_2 was used as a percolating solution. When distilled water was used the hydraulic conductivity was reduced to less than 1/100 of the value when the CaCl_2 solution was used.

The work of Bodman and Fireman (8) has shown that a satisfactory hydraulic conductivity could be maintained in a soil having an exchangeable sodium percentage of 30 providing a high electrolyte concentration could be maintained in the leaching solution. Quirk and Schofield (57) working on the same problem introduced the term "threshold concentration", which is the concentration of salt which causes a 10 - 15 per cent decrease in soil permeability. This is the concentration where factors which can cause drastic reduction in hydraulic conductivity are becoming operative. By using soils artificially saturated with sodium and calcium Quirk and Schofield measured the hydraulic conductivity of the soil to a series of solutions. These solutions were of different concentrations but all had the same sodium adsorption ratios which did not change the cation exchange complex. The concentration of electrolyte required to maintain satisfactory hydraulic conductivity (threshold concentration) for soils of different exchangeable sodium percentages is shown below in tabular form.

E.S.P.	Th. Conc. in m.e./litre
0	.6
5.8	2.3
8.9	4.1
21	9.5
35	18.6
100	250

The above results indicate that it should be possible to maintain the hydraulic conductivity of soils irrespective of the degree of sodium saturation by using a sufficiently strong electrolyte solution or by the addition of gypsum, etc. to the irrigation water. The authors indicated that the above table should be applicable to all semi-arid and arid regions.

A recent paper by Gardner et al. (28) presented results that indicate that electrolyte concentration has the same effect on nonsaturated flow as it has on saturated flow.

NATURE OF THE STUDY

This project was undertaken to determine the value of gypsum as an amendment for solonetzic soils, and the rates required to secure maximum results. The treatments consisted of leaching with tap water and with solutions supplying two, four, and eight tons of gypsum per acre. There were three parts to the study:

- (1) The effect of gypsum application on the physical and chemical characteristics of the soil was assessed in the laboratory by various analyses for soluble salts, exchangeable cations and physical conditions. The leachates from the leaching operations were analyzed to determine the order and magnitude of salt removal.
- (2) The effect of the various soil treatments on plant growth was measured by a pot test in the greenhouse. Attempts were made to reduce the effects of water availability and nutritional deficiencies.
- (3) The electrolyte concentrations required to maintain a satisfactory hydraulic conductivity during the leaching process was estimated by varying the concentration of gypsum in solution, and recording the time required for a certain volume of solution to pass through a pad of soil.

MATERIALS AND METHODS

THE SOILS

Ten soils were used in this study. They were taken from four Soil Zones in Alberta to get a wide range in climate, exchangeable sodium and parent material. The only similarities were that they were all solonetzic in nature and that the samples were all taken from the B₂ or B₃ horizon of the profile.

The following is a brief description of the four soil zones and of the soils used in the study.

The Black Soil Zone: The soils occurring in this zone are characterized by having seven inches or more of black A horizon with lime coming in at 36 inches. The area receives 15 to 20 inches of precipitation annually and has an average annual temperature of 32° to 39° F.

The soil series from this Soil Zone included in the study were the Wetaskiwin and the Daugh. These soils are developed from glacial lacustrine parent material on topography that is depressional to gently undulating.

The Wetaskiwin series is the solodized solonetz member of the catena. The sample used was taken from the B₂ horizon which is nearly black in color with pronounced staining. The structure is columnar with round tops and breaks into hard angular nuts.

The Daugh series is the solonetz member of the same catena. The sample used was taken from the B₂ horizon which is also dark colored and has vertical cleavage with strong columnar structure.

The Thin Black Soil Zone: The soils found in this zone are characterized by having 2 to 7 inches of black A horizon with lime appearing at about

30 inches. The area receives 14 to 18 inches of annual precipitation and has an average annual temperature of 33 to 40° F.

The soil series included in the study was the Killam which is developed from grey-brown till on topography which is usually quite level. The Killam soil series is the solodized solonetz member of the catena. The sample was taken from the B₂ horizon which is very dark brown in color and columnar in structure with round tops.

The Dark Brown Soil Zone: The soils in this area have a dark brown A horizon and may have a shallow layer of black soil on the surface. Lime is usually found about 24 inches from the surface. The annual precipitation in this zone is from 13 to 16 inches and the average annual temperature is from 33° to 41° F.

The soil series included in the project was the Halkirk which is developed from brown till on topography which is gently undulating to rolling. The Halkirk is the solodized solonetz of the catena. The sample was taken from the B₂ horizon which was very strongly columnar in structure.

The Brown Soil Zone: The soils in this zone have a dark brown to brown A horizon with lime coming in from 12 to 24 inches from the surface. The annual average precipitation is from 11 to 13 inches and the average annual temperature is 37° to 53° F.

The soil series included in this study were the Hemaruka, Halladay, Wardlow and Tilley. The Hemaruka and Halladay series are developed from glacial till parent material which contains varying amounts of Bearpaw shale. The topography on which these soils occur is level to rolling. The Hemaruka series is the solodized solonetz member of the catena. The sample used was taken from the B₂ horizon

Table 1

THE PHYSICAL AND CHEMICAL CHARACTERISTICS OF THE SOILS

Soil Series	Location	Hori- zon	Depth in inches	Mechanical analysis			Texture	Sat. % H.C.	Disturbed in./hr.	* capacity Ka/K _{sm} .e./100 gm.	Cation ex- change
				% S	% Si	% C					
Wetaskiwin	Vegreville	B2	5 $\frac{1}{2}$ -13	21	44	35	CL	68	nil	500	26.0
Daugh	Vegreville	B2	6-12	13	47	40	SiC-SiCL	67	nil	486	27.9
Killam	Daysland	B2	12-19	20	46	34	SiCL-CL	47	0.09	25	21.3
Halkirk	Castor	B2	7-12	40	23	37	CL	58	nil	7500	22.8
Hemaruka	Sunnynook	B2	5-9	37	26	37	CL	50	0.01	179	22.3
Halleday	Sunnynook	B2	13-26	40	41	19	L	35	0.26	8	19.0
Wardlow	Vauxhall	B2	7-15	50	28	22	SCL	42	0.15	13	15.0
Tilley	Vauxhall	B2	10-17	58	19	23	SCL	53	0.40	9	21.5
Wardlow	Tilley	B2	4-15	26	34	40	CL	52	0.10	47	21.9
Wardlow	Vauxhall	B _{sa}	15-20	27	42	31	CL	50	0.20	15	17.3

* air-water permeability ratio

Table 2

THE PHYSICAL AND CHEMICAL CHARACTERISTICS OF THE SOILS

Soil Series	pH	Electrical conductivity mmhos/cm.	Soluble salts in m.e./litre of saturation extract				Exchangeable cations in % of C.E.C.				Gypsum content tons/acre	Gypsum requirement tons/acre		
			Cations				Anions							
			Na ⁺	Ca ⁺⁺	Mg ⁺⁺	Cl ⁻	HCO ₃ ⁻	SO ₄ ⁼	Na ⁺	Ca ⁺⁺			K ⁺	Mg ⁺⁺
Wetaskiwin	7.1	6.5	66.5	3.5	5.5	1.1	7.2	47.3	37.3	18.1	2.7	41.9	nil	14.1
Daugh	6.7	2.0	14.6	2.5	1.1	1.1	4.2	13.2	16.1	36.2	2.1	45.6	nil	4.1
Killam	6.9	1.0	7.2	1.9	2.1	1.8	8.5	1.3	6.6	34.7	4.2	54.5	nil	nil
Halkirk *	7.8	2.2	28.5	2.5	0.7	1.1	13.6	17.5	20.4		3.1		nil	8.3
Hemaruka	7.7	2.1	27.2	3.2	0.3	3.1	13.3	15.8	19.7	35.9	8.5	36.9	nil	6.9
Halladay	6.7	0.8	7.0	1.0	0.1	2.0	3.4	2.8	10.9	55.3	8.4	25.4	nil	2.1
Wardlow *	8.0	5.7	61.0	5.5	7.0	6.9	10.4	57.8	22.7		4.7		nil	3.8
(Vauxhall)														
Tilley *	7.5	0.6	4.5	3.0	1.6	0.7	6.4	2.2	1.4		3.3		nil	nil
Wardlow *	7.6	1.9	15.2	2.7	1.1	6.3	8.3	1.5	13.7		6.8		nil	3.1
(Tilley)														
Wardlow *	8.0	11.4	115.0	26.5	36.0	7.4	9.5	16.5	21.4		4.6		15.4	nil
(Vauxhall)														

* These samples contained sufficient amounts of calcium and magnesium carbonates to prevent accurate determination of exchangeable calcium and magnesium.

which is dark brown in color and has structure which is columnar with roundtops. The Halladay series is the solodic member of the catena. The sample was taken from the B₂ horizon which is light brown in color and mildly columnar in structure.

The Wardlow and Tilley series are developed from alluvial lacustrine parent material on topography that is level to gently rolling. The Wardlow series is the solodized solonetz member of the catena and was sampled in two different locations. A sample was taken from the B₂ horizons of both locations and in one profile the B_{sa} horizon was sampled. The B₂ horizons were dark brown in color with strong columnar structure. The B_{sa} horizon contained visible amounts of salts, mainly gypsum. The Tilley series is the solodic member of the same catena. The sample was taken from the B₂ horizon which was light brown in color and mildly columnar in structure.

Chemical and physical characteristics of these ten soils are shown in Tables 1 and 2. The procedures used for these analyses are outlined in the section on methods.

METHOD OF LEACHING

The soil samples were air dried and passed through a 2 mm. sieve. Each sample was then divided into four equal portions by means of a sample splitter. One sub-sample from each series was set aside to be used as a reference and will be referred to as the untreated sample.

The procedure employed was to pass four acre feet of solution, on a weight basis, through the soil in one acre foot portions. Four solutions were used for leaching: (1) city tap water, (2) a solution containing enough dissolved CaSO₄·2H₂O to equal the total application

of two tons of gypsum per acre in four acre feet of water, (3) a solution containing $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ equivalent to four tons of gypsum per acre, and (4) one containing $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ equivalent to eight tons of gypsum per acre.

The analysis of the tap water used for leaching is given below:

Electrical conductivity in mmhos/cm.	0.2
pH	7.3
HCO_3^- in m.e./litre	0.7
Cl^- in m.e./litre	0.1
$\text{SO}_4^{=}$ in m.e./litre	1.6
Na^+ in m.e./litre	1.0
Mg^{++} in m.e./litre	0.6
Ca^{++} in m.e./litre	0.6

Only three treatments were used for each soil. For soils which had a low exchangeable sodium percentage the three lower treatments were used, viz. tap water, two tons of gypsum per acre and four tons of gypsum per acre. For soils having a high exchangeable sodium percentage the three higher rates were used, two tons, four tons and eight tons of gypsum per acre.

Specially made copper tension plates measuring fifteen inches square were used for the leaching operations. A brass screen and a piece of blotting paper was placed on the bottom of the plate and a 3800 gm. soil sample was spread uniformly on top of the blotting paper. The soil sample was then wetted from below with one acre foot of the desired solution to dispell entrapped air which may have hindered complete saturation of the sample. This solution was left on the sample

overnight in order to reach complete equilibrium with the soil.

The solution was drawn off the next morning and the next acre foot was applied and allowed to drain through the soil until the required amount of leachate, equivalent to one acre foot, was collected below. The outlet was then closed and the solution left in contact with the soil one hour before being drawn off. This procedure was repeated until four samples of leachate were collected, each equivalent to one acre foot of solution. Moderate suction was applied to remove excess solution during collection of the last portion.

The soils were left on the plates until the next morning and were then air dried and passed through a 2 mm. sieve. A portion of each sample was removed for analysis and the main portion set aside for the greenhouse experiment.

A sample from each acre foot of leachate was collected for chemical analysis. A few drops of toluene were added to each sample to inhibit the growth of microorganisms.

METHODS OF CHEMICAL ANALYSIS

The saturation percentage was calculated by measuring the amount of water required to bring a known weight of soil up to its saturation point. This value over the weight of oven dry soil times 100 is equal to the saturation percentage.

The pH of the soil extract and of the leachates was determined with a Beckman Model N2 pH meter. The readings were made at the carbon dioxide pressure of the atmosphere.

The electrical conductivity measurements of both the soil extracts and the leachates were made with a Solu Bridge and cell.

The carbonates, bicarbonates and chlorides were determined

according to the methods outlined in Agriculture Handbook 60 (73) with the slight modification of using a fresh sample for the chloride determination. According to Kolthoff and Sandell (44) the chloride titration must be carried out in neutral or slightly alkaline solution as in acid medium the sensitivity of the indicator decreases strongly with hydrogen ion concentration. The second ionization constant of chromic acid is small and therefore the chromate ions react with hydrogen ions, $\text{CrO}_4^{=}$ + $\text{H}^+ = \text{HCrO}_4^{=}$ and the decrease of the sensitivity is thus explained.

The cations sodium, calcium, potassium and magnesium in the leachates were determined with a Model DU Beckman spectrophotometer with a flame attachment according to the method used by the Soil Survey Laboratory in Alberta. Flooding solutions were used to reduce the error due to interference of other cations. The standards were made up using the sulfate form of the salt because most of the salts in these soils are in the sulfate form. It is realized that the determination of magnesium by the DU flame photometer is not too accurate. Ballantyne (2) found that it was possible to have errors up to 25 per cent at low magnesium concentrations.

The soil extracts were analyzed for sodium with the spectrophotometer, however the calcium and magnesium levels were determined by the versenate method outlined in Agriculture Handbook 60 (73).

The soluble sulfates were determined by the turbidimetric method described by Metson (51) using a Coleman Universal spectrophotometer Model 14.

The gypsum requirement and the gypsum content determinations were carried out according to the methods described in Agriculture Handbook 60 (73).

The total cation exchange capacities and the exchangeable cations of the soils were determined by the method used by the Soil Survey Laboratory at the University of Alberta. Exchangeable calcium and magnesium are not reported for the soils which were slightly calcareous because of the difficulty in removing all of the calcium carbonate. All results are corrected for soluble salts by subtraction of soluble cations determined on the saturation extract.

METHODS USED FOR PHYSICAL DETERMINATIONS

The mechanical fractions were determined by the modified pipette method outlined by Toogood and Peters (71). The air-water permeability ratios were determined according to the method worked out by Reeve (59). These determinations were carried out at the Drainage Division Laboratories at Vauxhall, Alberta, where the necessary apparatus is available. The disturbed hydraulic conductivity was calculated from the results obtained from the water permeability measurements necessary for calculating air-water permeability ratios.

The one-third and one atmosphere moisture contents were obtained by the use of a pressure plate according to the method outlined in Agriculture Handbook 60 (73). The modulus of rupture measurements were made on an apparatus similar to that described by Richards (60).

ELECTROLYTE CONCENTRATION AND PERMEABILITY

These determinations evolved from the work of Quirk and Schofield (57), the object being the establishment of a rough relationship between the exchangeable sodium percentages of nine different soils and the concentration of gypsum solution required to maintain permeability. These concentrations were then compared to the values obtained from the gypsum requirement determination.

The soil samples were passed through a 1/2 mm. sieve and placed in a permeameter tube, the bottom of which contained a pad of glass wool and a measured amount of sand. A piece of filter paper was placed on top of the soil to minimize disturbance of the soil surface. A constant head was maintained by the use of an inverted 100 ml. volumetric flask.

Two major modifications of the Quirk and Schofield procedure were: (1) Solutions of different concentrations of $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ were used instead of balanced solutions of calcium and sodium. (2) The time required for the equivalent of one acre foot of solution to be collected was the major measurement. This was done because the cation exchange status was constantly changing and therefore it was desirable for the same amount of each solution to pass through each soil. Thus, the only variable was the electrolyte concentration. The concentrations used for the measurements were the same as those used in the leaching of the larger samples. A total of six acre feet of solution was allowed to pass through each soil.

The results are expressed in much the same way as Quirk and Schofield expressed theirs, that is, in per cent decrease in permeability for each solution with time. The modifications described above gave rise to the necessity of expressing an increase in permeability in some cases, which is due to the changing cation exchange status, viz. Ca ions replacing Na ions to such an extent as to improve soil structure and thus increase the permeability rate.

THE GREENHOUSE STUDY

One quart plastic containers were used for the greenhouse study. Each pot contained: 100 grams of medium sand, a glass test

tube with a hole in the bottom opening into the sand and the top extending above the soil surface, and 900 grams of soil. The test tube facilitated alternate watering from top and bottom. This alternation of wetting procedure was an attempt to prevent salt accumulation in any one section of the pot. The pots were kept at a moisture content between 1/3 and one atmosphere tension by weighing daily. Ten barley seeds were planted after the initial wetting.

An application of 100 pounds of N, 60 pounds P_2O_5 and 75 pounds K_2O per acre was added to each pot. The total application was split into three portions and added at ten day intervals to minimize fixation. Each treatment was replicated twice and the barley was harvested after a growing period of 40 days. The green material was oven dried at a temperature of $60^{\circ}C$ for a period of 20 hours and weighed.

RESULTS AND DISCUSSION

I Leachate Study

The analysis of leachates in Tables 3 to 12 serves to illustrate the magnitude and order of salt removal during the leaching operation. Generally the pH of the leachates became lower as the gypsum treatment increased in concentration. The pH of the leachate obtained from the second acre foot of solution was usually the highest, which is probably due to increased hydrolysis of the sodium in the soil after most of the salts were removed. The electrical conductivity measurements indicate that the first acre foot of solution was more efficient in salt removal than the second, third or fourth acre foot.

The cation and anion concentrations in the leachates are very important in assessing the effect of reclamation procedures for alkali soils. Tables 3 to 12 show the cation concentration of the leachates after the application of various amounts of gypsum. Any differences between the total amounts of cations removed by the different gypsum treatments can be said to be the result of cation exchange reactions.

The addition of increasing amounts of gypsum increased the quantity of sodium in the leachate in all cases but one. This exception, which occurred during the application of 8 tons of gypsum per acre to the Hemaruka sample, is probably due to cracking of the sample during the leaching operation, allowing the solution to flow through the crack instead of through the entire soil mass. Tables 10 and 11, which show the leachate analysis for the Halkirk and Wetaskiwin samples,

respectively, point out that the replacement power of calcium for sodium can be very inefficient for soils containing considerable amounts of adsorbed sodium. Increasing the application of gypsum from 2 to 4 tons per acre on the Halkirk sample did not result in an increased removal of exchangeable sodium. In other words, an increased application of 4.35 m.e./litre of calcium resulted in no increase in sodium in the leachate. However, when the application was increased from 4 to 8 tons of gypsum, which is equivalent to 8.7 m.e./litre of calcium, the sodium content of the leachate increased from 56.8 to 65.2 m.e./litre, which is a difference of 8.4 m.e./litre. The Wetaskiwin sample behaved somewhat differently, as an increase in gypsum application of 2 tons resulted in the removal of 6.4 m.e./litre, while an increase of 4 tons of gypsum, equivalent to 8.7 m.e./litre of calcium resulted in the removal of a mere 2.4 m.e. of sodium per litre. These situations, in which the replacement of sodium by calcium is almost negligible, result in a very slight lowering of exchangeable sodium. This is shown in Table 14.

The highest applications of gypsum removed from 0.1 to 1.1 m.e./litre of potassium more than did the lowest applications. This is a negligible amount and therefore would have little effect on the exchangeable potassium percentage, which is substantiated by the exchange analysis in Table 14. Increasing gypsum applications result in increasing amounts of calcium in the leachate. This was to be expected. The data indicate that gypsum was quite effective in replacing magnesium, as amounts up to 12 m.e./litre were removed. However, as magnesium is one of the dominant adsorbed cations the total exchangeable magnesium percentage remained high.

The application of gypsum increased the quantities of cations

Table 3

ANALYSIS OF LEACHATES

Series *	Location *		Horizon *		Depth *		E.S.P. *		Zone *
Halladay	Sunnynook		B ₂		13-26"		10.9		Brown
Acre foot	E.C.	pH	Na ⁺	K ⁺	Ca ⁺⁺	Mg ⁺⁺	HCO ₃ ⁻	Cl ⁻	SO ₄ ⁼
Water									
1st	0.6	7.2	4.2	0.2	0.7	0.6	2.6	0.9	3.7
2nd	0.4	6.9	3.2	0.2	0.3	0.5	2.0	0.5	3.5
3rd	0.6	7.2	3.2	0.1	1.1	0.7	1.5	0.3	3.6
4th	0.6	7.4	3.9	0.1	0.4	0.5	1.4	0.9	3.0
Total			14.5	0.6	2.5	2.3	7.5	2.6	13.8
Total Gypsum Application of Two Tons/acre									
1st	1.0	7.1	5.6	0.3	2.0	1.3	1.9	0.7	6.6
2nd	0.8	7.3	5.6	0.2	1.0	0.7	1.5	0.3	6.2
3rd	0.8	7.4	6.0	0.2	0.6	0.7	1.9	0.2	5.7
4th	0.6	6.7	4.3	0.2	0.6	0.6	1.1	0.2	4.5
Total			21.5	0.9	4.2	3.3	6.4	1.4	23.0
Total Gypsum Application of Four Tons/acre									
1st	1.4	7.0	7.4	0.5	3.8	2.0	2.0	0.8	11.2
2nd	1.2	7.0	7.0	0.4	2.2	1.2	1.1	0.2	9.4
3rd	1.1	7.2	7.1	0.4	2.0	1.2	1.0	0.2	9.4
4th	1.1	7.2	5.1	0.4	2.4	1.4	0.8	0.2	8.2
Total			26.6	1.7	10.4	5.8	4.9	1.4	38.2

E.C. - electrical conductivity expressed in mmhos/cm.

Soluble salts expressed in m.e./litre

* This information is presented for the readers convenience.

Table 4

ANALYSIS OF LEACHATES

Series	Location		Horizon		Depth		E.S.P.		Zone
Hemaruka	Sunnynook		B ₂		5-9"		19.7		Brown
Acre foot	E.C.	pH	Na ⁺	K ⁺	Ca ⁺⁺	Mg ⁺⁺	HCO ₃ ⁻	Cl ⁻	SO ₄ ⁼
Total Gypsum Application of Two Tons/acre									
1st	1.7	7.6	4.4	0.4	2.1	2.1	8.0	1.7	10.6
2nd	1.0	7.7	8.8	0.2	0.7	0.8	4.0	0.2	5.8
3rd	0.9	7.8	7.0	0.2	0.9	0.6	2.8	0.1	5.6
4th	1.3	7.5	11.4	0.3	1.4	1.3	5.6	0.1	7.6
Total			41.6	1.1	5.1	4.8	20.4	2.1	29.6
Total Gypsum Application of Four Tons/acre									
1st	2.2	7.5	19.8	0.5	3.7	3.4	8.4	0.7	14.4
2nd	1.7	7.5	14.0	0.3	1.8	1.8	5.2	0.5	11.4
3rd	1.4	7.4	9.4	0.3	3.0	1.9	2.6	0.1	11.2
4th	1.5	7.3	9.6	0.3	2.7	2.1	2.7	0.1	11.2
Total			52.8	1.4	11.2	9.2	18.9	1.4	48.2
Total Gypsum Application of Eight Tons/acre									
1st	2.1	7.3	16.0	0.6	3.9	3.3	5.2	0.8	18.2
2nd	1.8	7.5	11.6	0.4	4.2	2.8	5.3	0.4	15.6
3rd	1.7	7.7	8.8	0.4	5.4	3.5	2.1	0.1	16.8
4th	1.8	7.5	9.8	0.4	5.4	3.5	2.6	0.0	16.0
Total			46.2	1.8	18.9	13.1	15.2	1.3	66.6

E.C. - electrical conductivity expressed in mmhos/cm.

Soluble salts expressed in m.e./litre

Table 5

ANALYSIS OF LEACHATES

Series	Location		Horizon		Depth		E.S.P.		Zone
Wardlow	Tilley		B ₂		4-15"		13.7		Brown
Acre foot	E.C.	pH	Na ⁺	K ⁺	Ca ⁺⁺	Mg ⁺⁺	HCO ₃ ⁻	Cl ⁻	SO ₄ ⁼
Total Gypsum Application of Two Tons/acre									
1st	1.6	7.4	10.8	0.3	3.6	2.1	5.2	3.0	10.0
2nd	1.1	7.3	8.4	0.2	1.7	1.0	3.2	0.8	7.2
3rd	0.8	7.6	6.1	0.2	1.3	0.5	1.7	0.1	6.1
4th	0.8	7.0	5.8	0.2	1.4	0.6	1.6	0.0	5.8
Total			29.1	0.9	8.0	4.2	11.7	3.9	29.1
Total Gypsum Application of Four Tons/acre									
1st	2.0	7.3	11.6	0.4	5.8	3.0	4.7	3.1	13.2
2nd	1.4	7.2	9.8	0.2	2.8	1.6	2.7	0.7	11.8
3rd	1.3	7.0	8.1	0.2	2.6	1.3	1.9	0.1	9.0
4th	1.2	6.9	6.7	0.2	3.1	1.6	1.9	0.0	9.6
Total			36.2	1.0	14.3	7.5	11.2	3.9	43.6
Total Gypsum Application of Eight Tons/acre									
1st	2.8	7.1	13.2	0.4	9.7	4.2	4.2	2.7	20.8
2nd	2.4	7.3	13.4	0.4	5.9	3.1	2.5	1.1	21.2
3rd	2.0	6.9	10.0	0.4	6.3	3.4	1.6	0.1	17.8
4th	2.0	7.0	8.0	0.4	7.6	4.0	1.7	0.0	17.6
Total			44.6	1.6	29.5	14.7	10.0	3.9	77.4

E.C. - electrical conductivity expressed in mmhos/cm.

Soluble salts expressed in m.e./litre

Table 1: Summary of data

Year	2010	2011	2012	2013	2014	2015	2016	2017	2018
Value	100	110	120	130	140	150	160	170	180

Year	2010	2011	2012	2013	2014	2015	2016	2017	2018
Value	100	110	120	130	140	150	160	170	180

Table 2: Summary of data

Year	2010	2011	2012	2013	2014	2015	2016	2017	2018
Value	100	110	120	130	140	150	160	170	180

Year	2010	2011	2012	2013	2014	2015	2016	2017	2018
Value	100	110	120	130	140	150	160	170	180

Table 3: Summary of data

Year	2010	2011	2012	2013	2014	2015	2016	2017	2018
Value	100	110	120	130	140	150	160	170	180

Year	2010	2011	2012	2013	2014	2015	2016	2017	2018
Value	100	110	120	130	140	150	160	170	180

Table 4: Summary of data

Year	2010	2011	2012	2013	2014	2015	2016	2017	2018
Value	100	110	120	130	140	150	160	170	180

Year	2010	2011	2012	2013	2014	2015	2016	2017	2018
Value	100	110	120	130	140	150	160	170	180

Source: Author's calculations based on data from the World Bank.

Note: All values are in US dollars.

Table 6

ANALYSIS OF LEACHATES

Series	Location		Horizon		Depth		E.S.P.		Zone
Wardlow	Vauxhall		B ₂		7-15"		22.7		Brown
Acre foot	E.C.	pH	Na ⁺	K ⁺	Ca ⁺⁺	Mg ⁺⁺	HCO ₃ ⁻	Cl ⁻	SO ₄ ⁼
Water									
1st	3.1	7.4	32.0	0.2	2.8	5.0	5.8	2.7	26.0
2nd	0.9	7.9	0.2	0.1	0.2	1.1	4.5	0.3	5.0
3rd	0.6	7.7	6.8	0.0	0.2	0.4	3.5	0.1	2.6
4th	0.9	7.8	8.0	0.0	0.3	0.5	2.8	0.2	6.8
Total			56.0	0.3	3.5	7.0	16.7	3.3	40.4
Total Gypsum Application of Two Tons/acre									
1st	3.4	7.2	34.0	0.2	5.4	5.9	7.6	1.4	30.0
2nd	1.1	7.3	10.8	0.1	0.5	1.1	4.5	0.2	7.6
3rd	0.9	7.1	8.8	0.1	0.1	0.5	3.3	0.1	6.4
4th	0.8	6.9	6.4	0.0	0.1	0.8	1.5	0.1	5.8
Total			60.0	0.4	6.1	8.3	16.9	1.8	49.8
Total Gypsum Application of Four Tons/acre									
1st	3.0	7.3	37.6	0.2	5.7	5.5	4.4	2.6	36.0
2nd	1.6	7.6	15.2	0.1	1.0	1.1	2.9	0.5	9.0
3rd	1.2	7.6	11.2	0.0	0.6	0.7	2.4	0.2	8.2
4th	1.3	7.6	10.4	0.1	1.8	1.4	1.7	0.2	10.1
Total			74.4	0.4	9.1	8.7	11.4	3.5	63.3
Total Gypsum Application of Eight Tons/acre									
1st	3.3	7.3	31.2	0.3	9.4	6.0	5.3	1.8	32.5
2nd	2.2	7.6	24.0	0.3	2.9	2.6	2.6	0.3	23.2
3rd	1.8	7.6	16.0	0.2	2.3	1.4	1.8	0.2	18.8
4th	1.8	7.6	16.8	0.1	4.2	1.6	2.6	0.2	20.0
Total			88.0	0.9	18.8	11.6	12.3	2.5	94.5

E.C. - electrical conductivity expressed in mmhos/cm.

Soluble salts expressed in m.e./litre

Table 7

ANALYSIS OF LEACHATES

Series	Location		Horizon		Depth		E.S.P.		Zone
Killam	Daysland		B ₂		12-19		6.6		Shallow Black
Acre foot	E.C.	pH	Na ⁺	K ⁺	Ca ⁺⁺	Mg ⁺⁺	HCO ₃ ⁻	Cl ⁻	SO ₄ ⁼
Water									
1st	0.8	6.5	5.4	0.3	1.3	3.0	3.7	0.4	5.6
2nd	0.5	6.6	3.7	0.2	0.8	1.3	2.5	0.3	3.6
3rd	0.4	6.7	2.5	0.1	0.4	0.8	1.6	0.2	2.0
4th	0.3	6.7	2.4	0.1	0.3	0.7	1.3	0.2	1.7
Total			14.0	0.7	2.8	5.8	9.1	1.1	12.9
Total Gypsum Application of Two Tons/acre									
1st	1.1	7.0	5.7	0.4	2.9	4.4	3.2	0.3	10.8
2nd	0.8	6.7	4.8	0.3	1.9	2.8	1.9	0.2	6.8
3rd	0.7	6.5	3.7	0.2	1.3	2.2	1.0	0.1	5.2
4th	0.7	6.5	3.2	0.2	1.3	2.2	0.6	0.1	5.2
Total			17.4	1.1	7.1	11.6	6.7	0.7	28.0
Total Gypsum Application of Four Tons/acre									
1st	1.4	6.7	6.3	0.5	4.0	6.1	2.7	0.3	13.2
2nd	1.2	6.8	5.8	0.4	2.9	4.5	1.5	0.2	9.4
3rd	1.1	6.7	4.4	0.3	3.0	3.9	1.0	0.2	9.4
4th	1.0	6.8	4.2	0.3	3.1	3.8	0.9	0.2	8.8
Total			20.7	1.5	13.0	18.3	6.1	0.9	40.8

E.C. - electrical conductivity expressed in mmhos/cm.

Soluble salts expressed in m.e./litre

Table 8

ANALYSIS OF LEACHATES

Series	Location		Horizon		Depth		E.S.P.		Zone
Wardlow	Vauxhall		B _{sa}		15-20		21.4		Brown
Acre foot	E.C.	pH	Na ⁺	K ⁺	Ca ⁺⁺	Mg ⁺⁺	HCO ₃ ⁻	Cl ⁻	SO ₄ ⁼
Water									
1st	8.5	7.1	61.6	0.5	42.8	27.2	5.4	2.8	120
2nd	6.0	7.0	44.8	0.4	18.6	16.2	3.0	0.9	74
3rd	3.4	7.0	16.2	0.3	16.4	12.6	1.7	0.2	41
4th	2.2	7.0	7.4	0.2	13.0	9.5	1.5	0.1	27
Total			130.0	1.4	90.8	65.5	11.6	4.0	262
Total Gypsum Application of Two Tons/acre									
1st	9.0	6.7	71.2	0.6	36.4	29.6	5.3	3.6	123
2nd	7.0	7.0	45.6	0.5	17.4	15.4	2.8	0.6	76
3rd	3.5	7.0	13.4	0.3	16.4	13.6	1.6	0.1	43
4th	2.6	7.0	6.4	0.2	18.2	12.0	1.3	0.0	34
Total			136.6	1.6	88.4	70.6	11.0	4.3	276
Total Gypsum Application of Four Tons/acre									
1st	9.0	7.0	62.4	0.5	49.0	29.6	5.0	3.4	132
2nd	6.5	7.3	53.6	0.4	20.8	15.8	2.9	0.9	88
3rd	3.5	7.2	16.6	0.3	18.2	12.6	1.5	0.2	45
4th	2.6	6.7	6.6	0.2	18.6	11.6	1.2	0.1	36
Total			139.2	1.4	107.1	69.6	10.6	4.6	301

E.C. - electrical conductivity expressed in mmhos/cm.

Soluble salts expressed in m.e./litre

Table 9

ANALYSIS OF LEACHATES

Series	Location		Horizon	Depth		E.S.P.		Zone	
Daugh	Vegreville		B ₂	6-12"		16.1		Black	
Acre foot	E.C.	pH	Na ⁺	K ⁺	Ca ⁺⁺	Mg ⁺⁺	HCO ₃ ⁻	Cl ⁻	SO ₄ ⁼
Water									
1st	1.4	6.9	14.4	0.1	1.7	1.3	2.6	0.3	12.0
2nd	0.5	7.0	6.4	0.0	0.1	0.6	1.5	0.3	2.6
3rd	0.3	7.2	4.2	0.0	0.0	0.3	1.3	0.3	1.8
4th	0.3	7.4	4.0	0.0	0.7	0.3	1.7	0.4	2.1
Total			29.0	0.1	2.5	2.5	7.1	1.3	18.5
Total Gypsum Application of Four Tons/acre									
1st	1.6	6.9	15.0	0.1	3.5	2.4	1.7	0.3	14.0
2nd	1.3	6.8	11.6	0.0	2.9	2.0	1.3	0.3	13.0
3rd	1.1	6.8	8.4	0.0	3.1	1.8	1.0	0.2	10.3
4th	1.0	6.8	6.9	0.0	2.8	1.7	1.0	0.2	9.2
Total			31.9	0.1	12.3	7.9	5.0	1.0	46.5
Total Gypsum Application of Eight Tons/acre									
1st	1.7	6.8	17.6	0.1	7.4	5.0	1.6	0.4	28.0
2nd	1.7	6.8	12.6	0.0	6.3	4.3	1.1	0.2	21.6
3rd	1.5	6.8	8.8	0.0	7.4	3.8	0.7	0.1	18.0
4th	1.3	6.8	8.1	0.0	7.0	3.6	0.7	0.1	17.2
Total			47.1	0.1	28.1	16.7	4.1	0.8	84.8

E.C. - electrical conductivity expressed in mmhos/cm.

Soluble salts expressed in m.e./litre

Table 10

ANALYSIS OF LEACHATES

Series	Location		Horizon		Depth		E.S.P.		Zone
Halkirk	Castor		B ₂		7-12"		20.4		Dark Brown
Acre foot	E.C.	pH	Na ⁺	K ⁺	Ca ⁺⁺	Mg ⁺⁺	HCO ⁻	Cl ⁻	SO ₄ ⁼
Total Gypsum Application of Two Tons/acre									
1st	2.1	7.8	14.0	0.1	3.3	1.1	10.0	0.2	13.6
2nd	1.8	8.0	16.8	0.1	1.8	0.7	10.2	0.2	9.6
3rd	1.4	7.8	13.6	0.0	0.9	0.4	8.4	0.2	5.4
4th	1.4	7.7	12.4	0.0	0.9	0.4	7.9	0.1	6.0
Total			56.8	0.2	6.9	2.6	36.5	0.7	34.6
Total Gypsum Application of Four Tons/acre									
1st	2.2	7.5	20.0	0.1	4.3	1.4	8.4	0.1	18.0
2nd	1.8	7.6	16.0	0.1	3.7	1.1	7.0	0.1	12.4
3rd	1.4	7.7	10.8	0.1	2.4	0.9	4.4	0.1	9.6
4th	1.4	7.8	10.0	0.1	3.0	1.0	3.9	0.1	9.3
Total			56.8	0.4	13.4	4.4	23.7	0.4	49.3
Total Gypsum Application of Eight Tons/acre									
1st	2.2	7.2	20.4	0.1	5.1	2.5	6.3	0.1	23.0
2nd	2.1	7.7	17.6	0.2	4.8	2.0	4.6	0.1	18.6
3rd	2.2	7.6	17.2	0.2	6.4	3.4	3.5	0.2	23.2
4th	1.7	7.7	10.0	0.1	5.9	1.6	2.8	0.1	14.4
Total			65.2	0.6	22.2	9.5	17.2	0.5	79.2

E.C. - electrical conductivity expressed in mmhos/cm.

Soluble salts expressed in m.e./litre

Table 11

ANALYSIS OF LEACHATES

Series	Location	Horizon	Depth	E.S.P.	Zone
Wetaskiwin	Vegreville	B ₂	5 $\frac{1}{2}$ - 13"	37.3	Black

Acre foot	E.C.	pH	Na ⁺	K ⁺	Ca ⁺⁺	Mg ⁺⁺	HCO ₃ ⁻	Cl ⁻	SO ₄ ⁼
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Total Gypsum Application of Two Tons/acre

1st	4.0	7.3	40.0	0.1	1.8	5.1	5.3	0.3	29.2
2nd	3.2	7.5	30.8	0.1	1.3	3.7	6.2	0.2	23.2
3rd	1.5	7.7	13.2	0.0	0.5	0.8	5.2	0.2	8.2
4th	1.3	7.8	12.4	0.0	0.3	0.5	5.7	0.2	7.0

Total			96.4	0.2	3.9	10.1	22.4	0.9	67.6
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Total Gypsum Application of Four Tons/acre

1st	4.1	7.0	40.0	0.1	3.2	5.2	3.6	0.3	35.6
2nd	3.6	7.1	34.4	0.1	2.6	4.9	4.0	0.1	28.4
3rd	1.8	7.2	16.2	0.0	0.8	1.2	4.1	0.1	11.6
4th	1.4	7.5	12.2	0.0	0.7	0.9	2.9	0.1	16.8

Total			102.8	0.2	7.3	12.2	14.6	0.6	120.3
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Total Gypsum Application of Eight Tons/acre

1st	4.7	6.9	42.4	0.1	5.5	6.6	3.1	0.2	46.5
2nd	3.8	7.0	33.6	0.1	4.2	5.8	2.7	0.1	36.2
3rd	2.4	7.0	17.8	0.1	4.1	4.6	2.2	0.1	20.8
4th	1.9	7.0	11.4	0.0	5.6	3.5	1.6	0.1	16.8

Total			105.2	0.3	19.4	20.5	9.6	0.5	120.3
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E.C. - electrical conductivity expressed in mmhos/cm.

Soluble salts expressed in m.e./litre

Table 12

ANALYSIS OF LEACHATES

Series	Location		Horizon		Depth		E.S.P.		Zone
Tilley	Vauxhall		B ₂		10-17"		1.4		Brown
Acre foot	E.C.	pH	Na ⁺	K ⁺	Ca ⁺⁺	Mg ⁺⁺	HCO ₃ ⁻	Cl ⁻	SO ₄ ⁼
Water									
1st	0.7	7.5	1.9	0.2	3.7	1.8	4.4	0.3	2.4
2nd	0.4	7.7	1.7	0.1	2.4	1.2	2.9	0.1	1.9
3rd	0.3	7.7	1.4	0.1	2.0	0.8	2.2	0.1	1.9
4th	0.3	7.7	1.3	0.1	1.7	0.7	1.9	0.1	1.6
Total			6.3	0.5	9.8	6.3	11.4	0.6	7.8
Total Gypsum Application of Two Tons/acre									
1st	1.0	7.5	2.2	0.2	6.0	2.7	4.0	0.2	6.3
2nd	0.8	7.4	2.2	0.2	5.0	2.2	3.3	0.1	5.8
3rd	0.8	7.4	1.9	0.2	4.2	2.0	2.3	0.0	5.7
4th	0.7	7.6	1.6	0.2	4.0	1.8	2.0	0.1	5.6
Total			7.9	0.8	19.2	8.7	12.6	0.4	23.4
Total Gypsum Application of Four Tons/acre									
1st	1.2	7.2	2.2	0.2	8.5	3.5	3.9	0.2	10.4
2nd	1.1	7.2	2.3	0.2	7.1	3.1	2.4	0.1	10.2
3rd	1.1	7.3	1.9	0.2	6.8	3.0	1.9	0.1	10.2
4th	1.1	7.3	1.5	0.2	6.8	2.8	1.9	0.1	10.8
Total			7.9	0.8	29.2	12.4	10.1	0.5	41.6

E.C. - electrical conductivity expressed in mmhos/cm.

Soluble salts expressed in m.e./litre

removed in the leachate, but the bicarbonate and chloride ion concentrations were decreased as the gypsum application was increased. This decrease in bicarbonate concentration is attributed to the formation of calcium carbonate which is relatively insoluble. The decrease in chloride concentration is not consistent and the quantities involved are small, therefore any suggestions for this decrease may be invalid. The fact that there was no increase in chloride concentration upon the addition of gypsum indicates that the possibility of anion exchange taking place is unlikely, or at least that the reaction is negligible.

II Effect of Leaching on the Soils

Chemical Changes in the Soil

The data in Table 13 show that the pH values were not greatly influenced by the gypsum treatments. Usually the highest treatment reduced the pH of the soil saturation extract by about 1/10 of one pH unit. This could be due to the buffering action of soil organic matter. The lowest gypsum treatment usually caused a slight increase in the pH of the extract.

The same data show that the soils containing the least total soluble salts were those leached with tap water. The soils leached with gypsum solution had a greater electrical conductivity than those treated with straight tap water, the magnitude of the increase depending on the amount of gypsum added.

In nine out of ten cases the soluble sulfate concentration of the treated soils was higher than the calcium concentration. This is probably partly the result of a higher sulfate content to begin with, and partly an exchange of adsorbed sodium and magnesium with calcium thus reducing the calcium concentration in the soil solution. This

Table 13

ANALYSIS OF SOILS SHOWING EFFECT OF LEACHING TREATMENTS

		Saturation extract determinations							
Soil Series	Treatment	pH	E.C.	Na ⁺	Ca ⁺⁺	Mg ⁺⁺	HCO ₃ ⁻	Cl ⁻	SO ₄ ⁼
Halladay	untreated	6.7	0.8	7.0	1.0	0.1	3.4	2.0	2.8
	water	6.9	0.5	5.4	0.7	0.1	1.9	1.2	3.0
	2 T/acre	6.8	0.6	5.1	1.9	0.1	2.7	0.7	3.8
	4 T/acre	6.6	0.9	4.5	4.6	0.8	1.9	0.4	7.8
Hemaruka	untreated	7.7	2.1	27.2	3.2	0.5	13.3	3.1	15.8
	2 T/acre	7.7	1.3	12.6	2.2	0.2	9.1	0.7	5.3
	4 T/acre	7.6	1.5	13.0	3.7	0.2	6.8	0.9	10.2
	8 T/acre	7.6	1.7	13.6	4.8	0.2	6.4	0.7	12.2
Wardlow (Tilley)	untreated	7.6	1.9	15.2	2.7	1.1	8.3	6.3	1.5
	2 T/acre	7.7	1.0	7.4	2.2	0.2	5.1	1.8	3.1
	4 T/acre	7.5	1.2	10.2	4.2	1.0	4.9	0.5	10.3
	8 T/acre	7.5	1.3	9.0	7.1	1.3	4.2	1.1	12.5
Wardlow (Vauxhall)	untreated	8.0	5.7	61.0	5.5	7.0	10.4	6.9	57.8
	water	8.3	1.1	11.8	0.7	0.2	7.2	1.5	4.3
	2 T/acre	8.3	1.1	12.0	1.2	0.2	8.0	1.1	4.5
	4 T/acre	8.1	1.5	12.4	2.5	1.0	6.8	0.7	8.0
	8 T/acre	8.0	1.6	11.2	4.4	3.1	5.1	0.6	13.4
Killam	untreated	6.9	1.0	7.1	1.9	2.1	8.5	1.8	1.3
	water	6.9	0.5	5.3	1.5	0.6	3.4	0.7	3.3
	2 T/acre	6.9	0.7	5.6	2.0	0.6	2.3	0.7	5.5
	4 T/acre	6.8	0.8	4.3	2.4	3.1	2.3	0.7	7.0

E.C. - electrical conductivity expressed in mmhos/cm.

Soluble salts expressed in m.e./litre

Table 13 (cont.)

ANALYSIS OF SOILS SHOWING EFFECT OF LEACHING TREATMENTS

Saturation extract determinations									
Soil Series	Treatment	pH	E.C.	Na ⁺	Ca ⁺⁺	Mg ⁺⁺	HCO ₃ ⁻	Cl ⁻	SO ₄ ⁼
Wardlow B _{sa}	untreated	8.0	11.4	115.0	26.5	36.0	9.5	7.4	165.0
	water	7.9	2.7	18.0	20.3	8.1	2.3	0.9	45.2
	2 T/acre	7.9	3.0	16.8	26.2	10.9	2.3	0.9	51.3
	4 T/acre	7.9	3.1	16.5	28.3	10.7	1.9	0.7	52.3
Daugh	untreated	6.7	2.0	14.6	2.5	1.1	4.2	1.1	13.2
	water	6.8	0.7	6.0	0.2	0.2	2.7	1.1	3.0
	4 T/acre	6.7	1.0	7.5	1.2	0.2	2.7	0.7	5.7
	8 T/acre	6.6	1.3	10.8	2.9	2.1	2.3	0.7	13.1
Halkirk	untreated	7.8	2.2	28.5	2.5	0.7	13.6	1.1	17.5
	2 T/acre	7.9	1.5	14.8	2.5	0.3	8.7	1.3	7.6
	4 T/acre	7.9	1.9	15.9	3.0	0.5	6.8	1.3	11.2
	8 T/acre	7.8	2.1	25.5	4.0	1.0	6.1	1.3	22.0
Wetaskiwin	untreated	7.1	6.5	66.5	3.5	5.5	7.2	1.1	47.3
	2 T/acre	7.1	1.5	14.8	1.0	1.0	5.3	1.1	11.4
	4 T/acre	7.1	1.9	16.0	1.2	0.7	6.1	1.3	11.0
	8 T/acre	7.1	2.4	27.3	2.0	1.0	4.9	1.3	24.6
Tilley	untreated	7.5	0.6	4.5	3.0	1.5	6.4	0.7	2.2
	water	7.6	0.5	3.8	3.0	0.9	4.5	0.7	0.5
	2 T/acre	7.6	0.6	3.7	3.5	1.5	5.3	0.7	1.4
	4 T/acre	7.7	0.8	4.8	4.8	2.1	4.9	1.1	3.5

E.C. - electrical conductivity expressed in mmhos/cm.

Soluble salts expressed in m.e./litre

reaction is partly substantiated by a higher soluble sodium and magnesium content in the soils treated with higher applications of gypsum than those treated with water or low gypsum applications. A possible explanation for the Tilley profile reacting differently is that very little sodium was present originally as the soil was likely saturated with Ca and Mg. Thus very little calcium would be adsorbed and the concentration would not be reduced. Another possible explanation for the greater concentration of sulfate than calcium ions is that the calcium may have reacted with the bicarbonate ion, which is greatly reduced as the gypsum concentration is increased, to form the very slightly soluble compound, calcium carbonate.

In general the treatments reduced the quantity of soluble sodium and bicarbonates in the saturation extract of all the soils. In most cases the concentration of soluble calcium was increased when the highest rate of gypsum was added. The soluble magnesium was reduced by the water treatment, however, when gypsum was added the soil solution increased in magnesium content if the concentration of soluble magnesium was low initially. This is probably the result of the calcium releasing magnesium from the exchange complex. However, if the soluble magnesium concentration in the original soil was high the treatments reduced the amount of soluble magnesium. The concentration of soluble chlorides was reduced by leaching in seven out of ten cases. The other three which were very low in chlorides initially tended to increase slightly in chloride content after leaching.

The objective of most alkali reclamation projects is the reduction of sodium on the exchange complex. Therefore, the quantitative aspect of exchangeable sodium is of prime importance and is

Table 14

ANALYSIS OF SOILS SHOWING EFFECT OF LEACHING TREATMENTS

Soil Series	Treatment	Per cent exchangeable cations				Sodium ad- sorption ratio	Gypsum requirement tons/acre
		Na ⁺	K ⁺	Ca ⁺⁺	Mg ⁺⁺		
Halladay	untreated	10.9	8.4	55.3	25.4	8.4	2.1
	water	8.3	8.3	56.9	26.5	9.1	1.0
	2 T/acre	4.4	8.3	60.8	26.5	5.2	0.3
	4 T/acre	1.6	8.1	64.3	26.0	2.7	nil
Hemaruka	untreated	19.7	8.5	35.9	36.9	20.6	6.9
	2 T/acre	12.2	7.6	41.0	39.2	11.8	3.1
	4 T/acre	11.2	6.1	47.2	35.5	9.4	1.7
	8 T/acre	11.5	6.2	50.9	31.4	8.6	2.1
Wardlow (Tilley)	untreated	13.7	6.8	*	*	11.0	3.1
	2 T/acre	7.7	6.9			6.8	nil
	4 T/acre	4.9	6.8			6.3	nil
	8 T/acre	3.3	6.8			4.4	nil
Wardlow (Vauxhall)	untreated	22.7	4.7			24.4	3.8
	water	19.0	4.8			16.7	1.7
	2 T/acre	18.9	4.8			13.9	1.4
	4 T/acre	13.0	4.8			9.4	1.7
	8 T/acre	5.4	5.4			5.8	nil
Killam	untreated	6.6	4.2	34.7	54.5	5.1	nil
	water	4.2	4.2	35.6	56.2	6.1	nil
	2 T/acre	2.3	3.7	41.4	52.6	4.9	nil
	4 T/acre	1.4	3.7	43.7	51.2	2.6	nil

* Exchangeable calcium and magnesium determinations are omitted for calcareous soils.

Table 14 (cont.)

ANALYSIS OF SOILS SHOWING EFFECT OF LEACHING TREATMENTS

Soil Series Treatment	Per cent exchangeable cations				Sodium ad- sorption ratio	Gypsum requirement tons/acre
	Na ⁺	K ⁺	Ca ⁺⁺	Mg ⁺⁺		
Wardlow B _{sa} untreated	21.4	4.6	*	*	20.6	nil **
water	5.7	4.4			4.8	nil
2 T/acre	1.2	4.4			3.9	nil
4 T/acre	0.6	4.4			3.7	nil
Daugh untreated	16.1	2.1	36.2	45.6	10.9	4.1
water	12.7	2.2	47.6	37.5	10.1	0.3
4 T/acre	10.2	2.2	50.4	37.2	8.7	1.7
8 T/acre	6.5	1.8	53.2	38.5	6.8	0.3
Halkirk untreated	20.4	3.1	*	*	22.2	8.3
2 T/acre	18.4	3.2			12.5	3.4
4 T/acre	19.1	3.2			12.0	3.4
8 T/acre	15.4	3.2			16.1	3.2
Wetaskiwin untreated	37.3	2.7	18.1	41.9	31.4	14.1
2 T/acre	25.8	2.7	27.3	44.2	14.8	9.3
4 T/acre	25.9	2.8	32.4	38.9	16.0	8.6
8 T/acre	23.1	2.7	35.7	38.5	22.3	8.6
Tilley untreated	1.4	3.3	*	*	3.0	nil
water	0.5	3.2			2.7	nil
2 T/acre	0.5	3.2			2.3	nil
4 T/acre	0.5	3.2			2.6	nil

* Exchangeable calcium and magnesium determinations are omitted for calcareous soils.

** This soil sample had a gypsum requirement of 15.4 tons/acre.

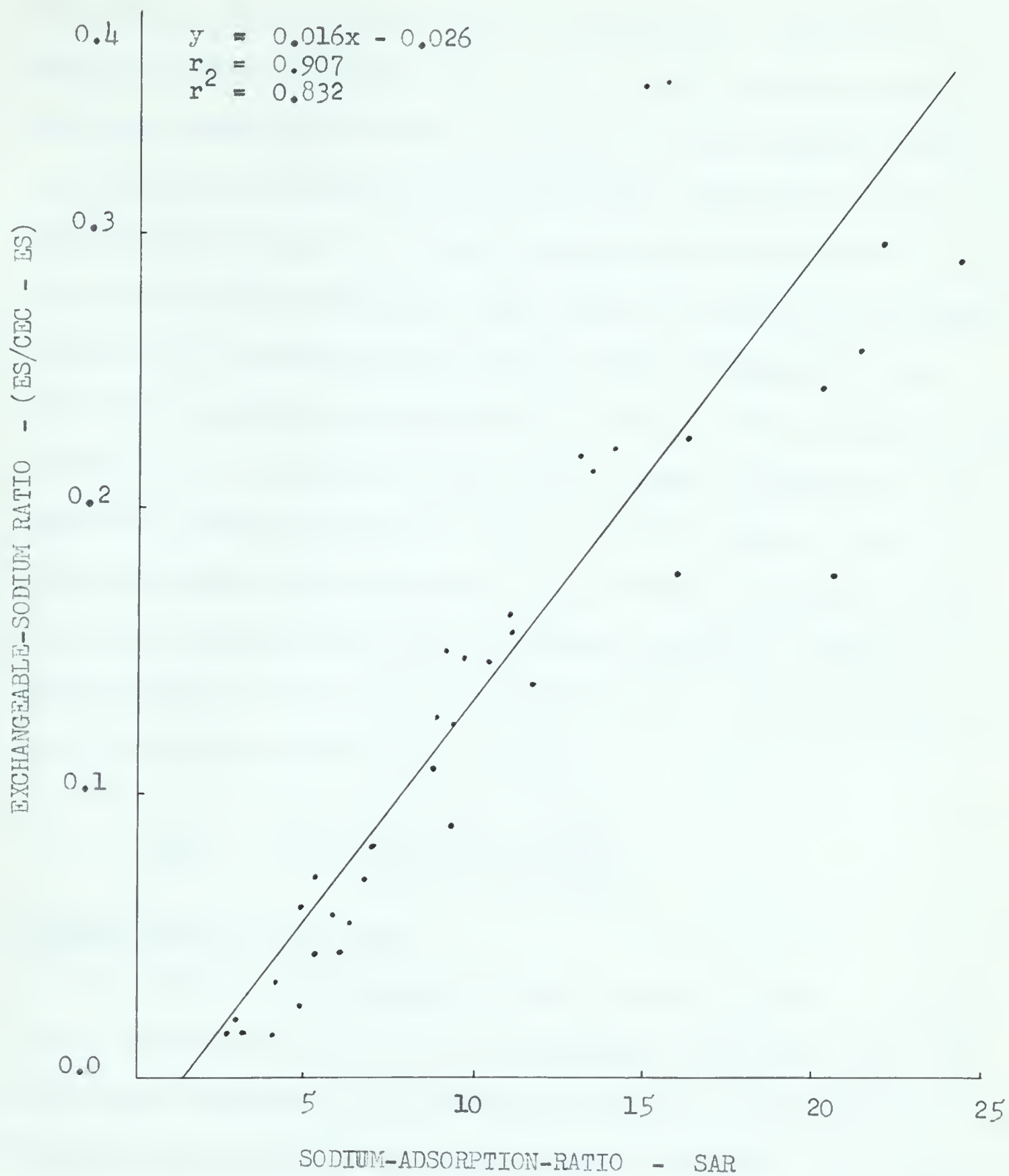
shown in Table 14. The exchangeable sodium content of all ten soils was lowered by the gypsum treatments. The Hemaruka, Halkirk and Wetaskiwin soils retained appreciable amounts of sodium on the exchange complex even after being treated with 8 tons of gypsum per acre. It is apparent that complete chemical reclamation was not achieved in these three soils. This is substantiated by the gypsum requirement figures which show that although 8 tons of gypsum had been applied there is still a need for additional calcium.

The gypsum requirement figures indicate that the exchange of calcium for sodium is not 100% efficient, for although the gypsum requirement for the Halkirk soil was 8.3 tons per acre before treatment, it still had a requirement of 3.2 tons per acre after 8 tons had been added. This is also true of the Hemaruka and Wetaskiwin soils. However, after the requirement for gypsum had been applied to the Hemaruka and Wetaskiwin soils the physical conditions were greatly improved. From a structural standpoint, as shown by the water permeability ratio in Table 15, one would say that the soils have been reclaimed. The only sample that was not reclaimed is the Wetaskiwin, which has a gypsum requirement of 14.1 tons per acre. This amount was not applied with the result that the exchangeable sodium percentage was not reduced below 23 and the physical conditions are still far from satisfactory.

Exchangeable potassium and magnesium contents were only slightly reduced in most cases, while exchangeable calcium was increased to the approximate extent of the decrease in exchangeable sodium content.

Sodium Adsorption Ratios and Exchangeable Sodium Percentage

Agriculture Handbook 60 (73) defines the sodium adsorption ratio as $Na^+ / \sqrt{(Ca^{++} + Mg^{++})/2}$, where Na^+ , Ca^{++} and Mg^{++} refer to



Exchangeable-sodium ratio (ES/CEC - ES) as related to the sodium-adsorption-ratio (SAR) of the saturation extract.

ES - exchangeable sodium
CEC - cation exchange capacity

Fig. 1

the concentrations of the designated soluble cation expressed in milliequivalents per litre. This ratio is often used as an approximation of exchangeable sodium percentage. It was thought desirable to calculate the correlation coefficient and a regression equation for the agreement between the sodium adsorption ratio (SAR) shown in Table 14 and the exchangeable sodium ratio which is the ratio of exchangeable sodium to the (cation exchange capacity minus exchangeable sodium). This relationship is shown graphically in Fig. 1. The correlation calculation gave an r value of 0.907 which is highly significant. The regression equation was found to be $y = -0.026 + 0.016 x$ where y is the exchangeable sodium ratio and x is the SAR. To use this equation to estimate exchangeable sodium percentage it should be expressed in a manner similar to that used in Handbook 60 (73). The relationship between the ESP and SAR is given by the equation

$$\text{ESP} = \frac{100 (0.016 \text{ SAR} - 0.026)}{1 + (0.016 \text{ SAR} - 0.026)}$$

Physical Changes in the Soil

Baver's (4) statement that soil structure plays an important role in determining water and air relationships within the plant root zone, places emphasis on the following discussion of the physical changes brought about in the soil by the application of gypsum. These changes were measured by air-water permeability ratios, disturbed hydraulic conductivity measurements and 1/3 atmosphere moisture contents which are tabulated in Table 15. The crusting tendencies of the soils, measured by modulus of rupture, are shown in Table 16 and are partly discussed in another section.

The air-water permeability ratios are a measure of the

stability of aggregates when subjected to wetting; low values are associated with good stability while high values indicate poor stability. The Daugh, Hemaruka, Halkirk and Wetaskiwin soils were the only ones that had poor aggregate stability initially. The air-water permeability ratio of the Hemaruka was lowered to an acceptable value with the application of 4 tons of gypsum, while 8 tons per acre was required to lower the ratio a similar amount in the Daugh and Halkirk soils. The application of 8 tons of gypsum per acre was not effective in lowering the value for the Wetaskiwin sample. Gypsum was effective in lowering the ratio value of the other 6 soils even though their initial values were quite low. The slight increase in air-water permeability ratio when the Halladay soil was leached with water indicates that the soil colloids were somewhat dispersed when the salt content was lowered.

The disturbed hydraulic conductivity measurements, which were run on 1 mm. soil, show trends similar to the air-water permeability ratios. Gypsum was effective in increasing the hydraulic conductivity of all the soils except the Wetaskiwin sample, the hydraulic conductivity of which was not measureable at any time.

The data for $1/3$ atmosphere moisture content supports the findings of Carroll and McHenry (14), who report that increased dispersion of soil colloids increases the moisture equivalent. This phenomenon is probably due to the increase in surface area and the high hydration associated with the sodium ion. The data in Table 15 show that the application of gypsum has generally lowered the moisture equivalent as determined by the $1/3$ atmosphere procedure. In several cases, however, the lowest gypsum treatment has resulted in an increase in the moisture equivalent, especially for the Wetaskiwin soil. This

Table 15

EFFECT OF LEACHING ON SOIL PROPERTIES

Soil Series	Treatment	Air-water permeability ratio.	Disturbed hydraulic conductivity. inches/hr.	1/3 atmosphere moisture percentage.
Halladay	untreated	8	0.26	27.7
	water	13	0.29	27.6
	2 tons gyp.	9	0.24	27.1
	4 tons gyp.	8	0.61	26.6
Hemaruka	untreated	179	0.01	37.4
	2 tons gyp.	83	0.05	38.3
	4 tons gyp.	23	0.27	34.8
	8 tons gyp.	20	0.40	33.7
Wardlow (Tilley)	untreated	47	0.10	34.5
	2 tons gyp.	23	0.14	34.3
	4 tons gyp.	13	0.22	33.5
	8 tons gyp.	13	0.32	32.7
Wardlow (Vauxhall)	untreated	13	0.15	24.6
	water	12	0.28	27.6
	2 tons gyp.	13	0.29	26.1
	4 tons gyp.	6	0.76	23.0
	8 tons gyp.	6	0.64	22.3
Killam	untreated	25	0.09	28.3
	water	15	0.45	27.3
	2 tons gyp.	10	0.67	27.0
	4 tons gyp.	7	0.88	24.8

Table 15 (cont.)

EFFECT OF LEACHING ON SOIL PROPERTIES

Soil Series	Treatment	Air-water permeability ratio.	Disturbed hydraulic conductivity. inches/hr.	1/3 atmosphere moisture percentage.
Wardlow B _{sa}	untreated	15	0.20	27.0
	water	7	0.60	25.7
	2 tons gyp.	8	0.56	25.8
	4 tons gyp.	7	0.80	24.0
Daugh	untreated	486	nil	36.8
	water	209	0.01	39.5
	2 tons gyp.	89	0.02	34.5
	4 tons gyp.	35	0.12	32.5
Halkirk	untreated	500+	nil	40.9
	2 tons gyp.	120	0.05	38.8
	4 tons gyp.	122	0.27	37.7
	8 tons gyp.	28	0.40	34.2
Wetaskiwin	untreated	500+	nil	38.9
	2 tons gyp.	500+	nil	43.8
	4 tons gyp.	500+	nil	42.8
	8 tons gyp.	500+	nil	41.9
Tilley	untreated	9	0.40	25.9
	water	8	0.56	26.9
	2 tons gyp.	9	0.52	25.3
	4 tons gyp.	8	0.48	25.9

observation, coupled with the fact that these treatments reduced the exchangeable sodium content, tend to indicate that the major factor responsible for this increase in moisture equivalent is that of dispersion and increased surface area. The air-water permeability ratio and the hydraulic conductivity measurements, however, tend to contradict this assumption because these treatments indicate less dispersion for the same samples.

Electrolyte Concentration and Permeability

The effect of the gypsum concentrations on permeability is shown in Fig. 2. The concentrations required to maintain permeability were derived from these graphs by estimating the concentration which would result in no more than a 15 per cent decrease in permeability. The first graph in Fig. 2, the Halladay sample, will serve as an example. A gypsum concentration of 4.35 m.e./litre resulted in a 22 per cent decrease in permeability, therefore it was estimated that 5 m.e./litre would result in a permeability decrease of 15 per cent. This concentration, 5 m.e./litre, is the threshold concentration. It is realized that considerable error may result from these estimations and that a correlation coefficient would be misleading. These estimated concentrations are expressed in both m.e./litre and tons/acre when four acre feet of solution are applied. These results are compared with results obtained from a graphical interpretation of Quirk and Schofield's results which are shown on page 24, and also with the gypsum requirement measurements. These comparisons are shown below.

Effect of gypsum concentration on hydraulic conductivity
during the application of six acre feet of solution.

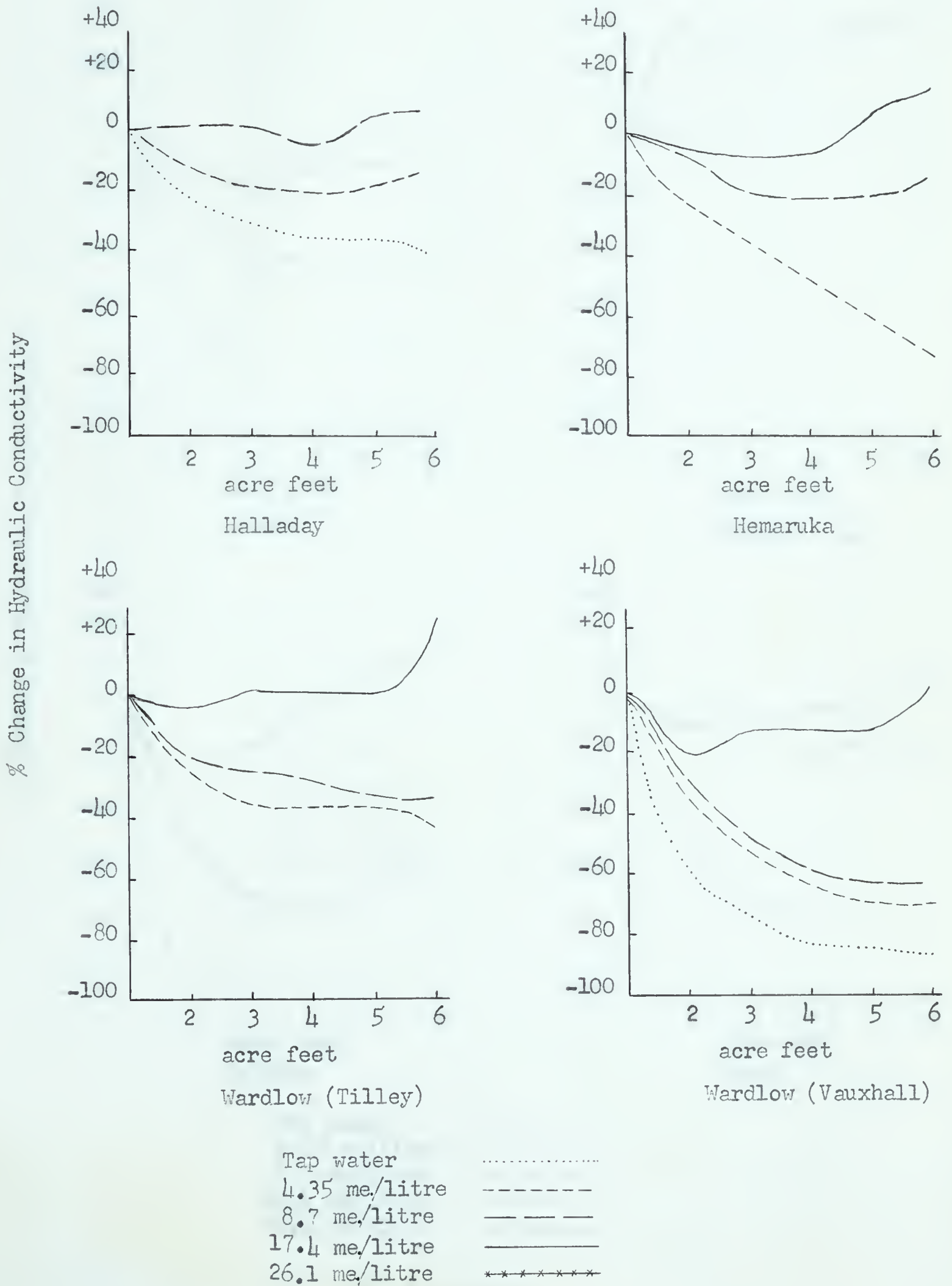


Fig. 2

Effect of gypsum concentration on hydraulic conductivity
during the application of six acre feet of solution.

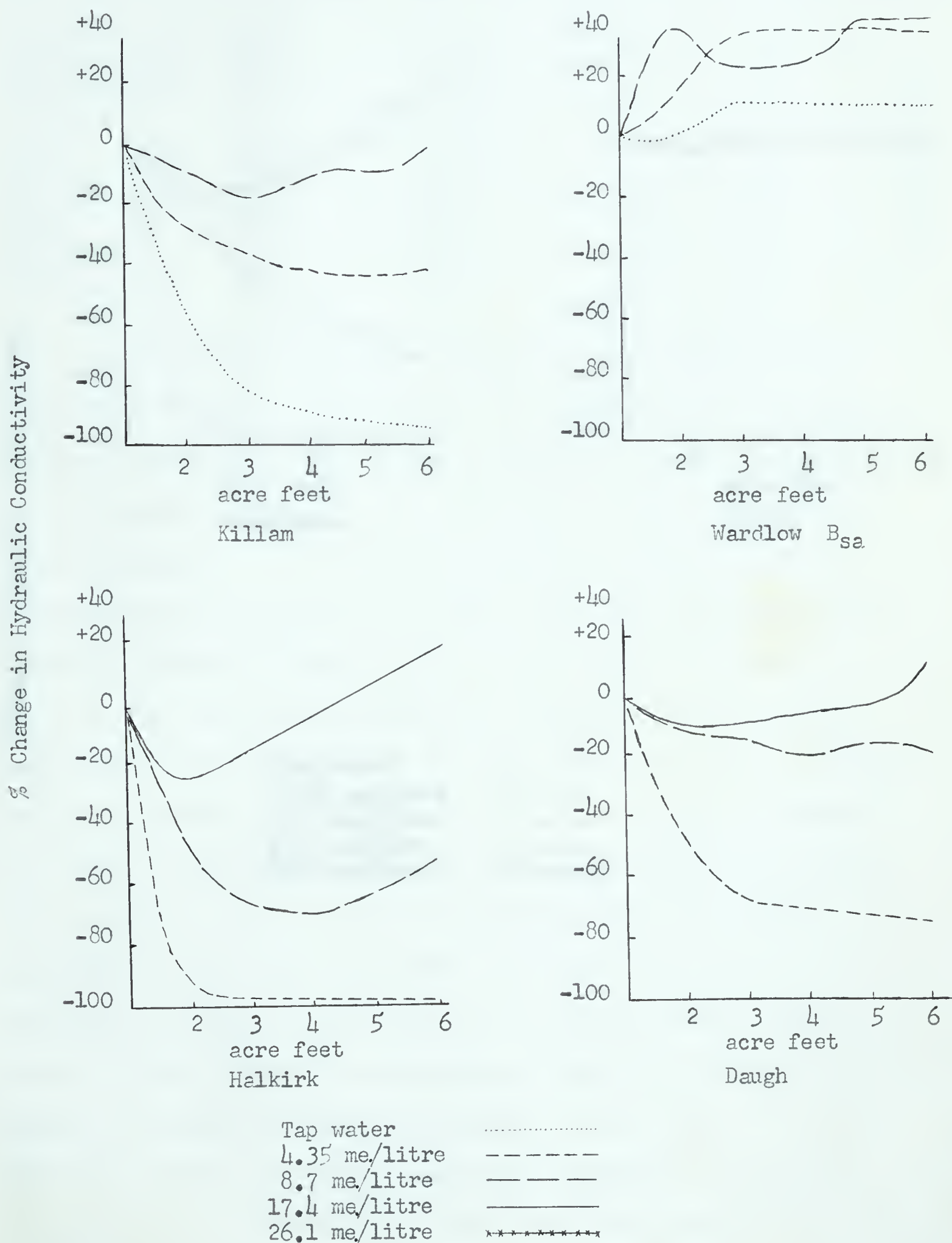


Fig. 2 (cont.)

Effect of gypsum concentration on hydraulic conductivity
during the application of six acre feet of solution.

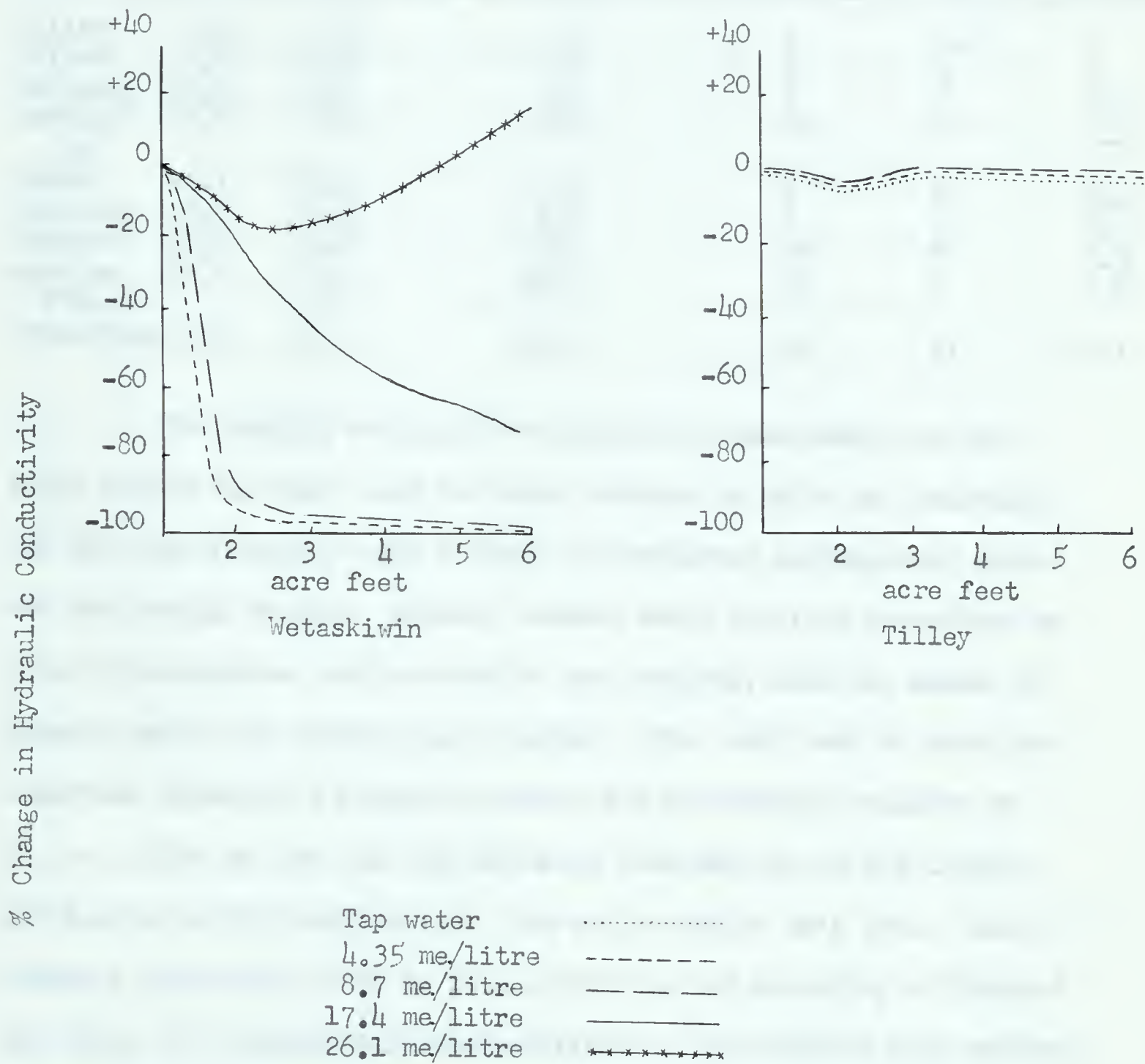


Fig. 2 (cont.)

Soil	E.S.P.	Exchange- able sodium m.e./100 gm.	Threshold conc. Quirk and Schofield m.e./litre	Threshold conc. from this study m.e./l	Tons/acre	Gypsum Requirement Tons/acre
Tilley	1.4	.3	.4	1	0.5	0
Killam	6.6	1.4	2.5	5	3	0
Halladay	10.9	2.1	5.0	5	2	2.1
Wardlow (Ty)	13.7	3.0	6.2	10	6	3.1
Daugh	16.1	4.6	7.5	9	4	4.1
Hemaruka	19.7	4.4	9.0	9	4	6.9
Halkirk	20.4	4.6	9.4	15	7	8.3
Wardlow (Vaux)	22.7	3.4	10.8	13	6	3.8
Wetaskiwin	37.3	9.7	19.0	24	11	14.1

The results obtained for threshold concentration in this study follow the same trend as those obtained by Quirk and Schofield, but are more irregular with respect to increasing exchangeable sodium and are usually higher. Several factors could possibly contribute to these discrepancies such as kind of clay mineral, kind and amount of organic matter and initial salt content. The soil used by Quirk and Schofield contained 2% organic carbon, had an exchange capacity of 10.1 m.e./100 gm. and the clay minerals were made up of 40% illite, 40% kaolin and 20% vermiculite. The soils used in this study have exchange capacities of 15 to 27 m.e./100 gm. and according to Mathieu¹ the clays are predominately montmorillonite. The initial salt content could promote a greater initial permeability, and as the graphs are constructed on the basis of per cent reduction of the initial permeability, this initial value could greatly influence the final results and increase the threshold concentration. On the other hand, one could expect the threshold concentration obtained in this study to be less than that of Quirk and Schofield because a gypsum solution was used instead of a balanced solution of sodium and calcium that was in equil-

¹ Personal communication.

ibrium with the exchange complex.

The comparison between threshold concentration obtained in this study and the gypsum requirement, provided that four acre feet of solution is applied, indicate that in the majority of cases the gypsum requirement figure is adequate to maintain permeability. However, as the gypsum requirement is affected considerably by the exchange capacity, this characteristic should be taken into account when gypsum requirements are used as criteria in reclamation. This can best be illustrated by the Wardlow (Vaux.) sample for which the threshold concentration is 6 tons per acre while the gypsum requirement is only 3.8 tons. Reference to Table 1 shows the cation exchange capacity of this sample to be only 15 m.e./100 gm. which is quite low in relation to the other samples. This can be more readily seen in the Table on page 65 which shows the exchangeable sodium content to be 3.4 m.e./100 gm. which is also relatively low in comparison with the other soils with equivalent exchangeable sodium percentages.

The Wardlow B_{sa} sample tends to make one optimistic about the use of chemicals in the reclamation of solonetzic soils. This sample contains 15.4 tons of gypsum per acre foot of soil. This quantity of naturally occurring gypsum was effective in maintaining the permeability during leaching without supplementary applications to the leaching solution. This occurrence of gypsum under the B_2 or B_3 of solodized solonetz is not uncommon in Alberta¹. This may indicate that the problem of reclaiming solonetzic soils is concerned only with the surface horizons. This accumulation of gypsum also suggests more investigation into the possibility of deep plowing to bring this material to the surface.

The above results indicate that it should be possible to

1 Personal correspondence from R. A. Milne.

maintain permeability during reclamation irrespective of the exchangeable sodium content of the soil by using solutions of electrolyte of sufficient concentration. This theory may limit the use of gypsum in reclamation of high sodium soils. The solubility of gypsum in the field is not exactly known, and is affected by its purity, its degree of fineness, the presence of common ions which would reduce its solubility, and the presence of unlike ions which would increase its solubility. Quirk and Schofield (57) estimate its solubility in actual practice to be about half that of its saturated concentration. This concentration would be about 15.2 m.e./litre or about 1.75 tons per acre foot of water. Therefore, the maximum gypsum application possible during the application of four acre feet of water would be 7 tons per acre. Agriculture Handbook 60 (73) suggests that only 5 tons of gypsum would be soluble in four acre feet of water. The foregoing data, therefore, indicate that the effectiveness of gypsum in the reclamation of solonchic soils is limited when the exchangeable sodium percentage of the soil is above an approximate value of 20 or 25, depending upon the actual solubility of gypsum in the field.

Effect of Gypsum Treatments on Plant Growth

The effect of the gypsum treatments on germination, modulus of rupture and barley yields are tabulated in Table 16. In all cases the application of higher rates of gypsum lowered the strength of the soil crust which is measured by the modulus of rupture. Low rates of application, however, increased the modulus of rupture in some cases. Leaching soils which have an exchangeable sodium percentage of about 10 to 16 with water resulted in an increase in modulus of rupture, while leaching soils having an exchangeable sodium percentage over 16 with

Table 16

THE EFFECTS OF GYPSUM ON THE GERMINATION AND YIELD
OF BARLEY, AND THE MODULUS OF RUPTURE OF THE SOIL

Soil Series	Treatment	Percent germination	Modulus of rupture millibars/cm.	Unadjusted yield in gms.	Adjusted yield in gms.
Halladay	untreated	80	787	1.8	2.6
	water	75	1496	1.7	2.3
	2 tons gyp.	90	742	2.4	2.7
	4 tons gyp.	100	288	2.7	2.7
Hemaruka	untreated	70	1713	1.2	1.6
	2 tons gyp.	60	1341	1.1	2.0
	4 tons gyp.	100	567	2.2	2.3
	8 tons gyp.	100	321	2.7	2.7
Wardlow (Tilley)	untreated	90	412	2.7	2.9
	2 tons gyp.	95	276	2.6	2.7
	4 tons gyp.	90	169	2.4	2.8
	8 tons gyp.	100	152	2.9	2.9
Wardlow (Vaux.)	untreated	90	646	2.2	2.3
	water	45	2325	1.8	2.6
	2 tons gyp.	75	804	2.1	2.8
	4 tons gyp.	100	551	2.2	2.2
	8 tons gyp.	100	459	2.5	2.5
Killam	untreated	100	1226	2.4	2.4
	water	100	506	2.3	2.3
	2 tons gyp.	100	587	2.5	2.5
	4 tons gyp.	95	325	2.4	2.5

Table 16 (cont.)

THE EFFECTS OF GYPSUM ON THE GERMINATION AND YIELD
OF BARLEY, AND THE MODULUS OF RUPTURE OF THE SOIL

Soil Series	Treatment	Percent germination	Modulus of rupture millibars/cm	* Unadjusted yield in gms.	** Adjusted yield in gms.
Wardlow B _{sa}	untreated	100	723	2.1	2.1
	water	90	749	2.7	3.0
	2 tons gyp.	95	269	2.8	2.9
	4 tons gyp.	100	158	2.7	2.7
Daugh	untreated	55	2605	1.3	2.4
	water	75	3195	1.6	2.1
	4 tons gyp.	95	2135	2.2	2.3
	8 tons gyp.	100	450	2.0	2.0
Halkirk	untreated	90	2948	1.7	1.9
	2 tons gyp.	80	1661	2.4	3.1
	4 tons gyp.	100	897	2.9	2.9
	8 tons gyp.	80	474	2.8	3.7
Wetaskiwin	untreated	35	2315	0.4	1.2
	2 tons gyp.	75	7653	0.7	1.0
	8 tons gyp.	85	1797	2.6	3.1
Tilley	untreated	100	177	2.4	2.4
	water	100	144	2.5	2.5
	2 tons gyp.	100	121	2.4	2.4
	4 tons gyp.	100	120	2.2	2.3

* Unadjusted yield refers to the average yield obtained from two pots.

** Adjusted yield is the calculated yield adjusted for the number of plants in each pot.

the lower rate of gypsum had the same effect. This is probably the result of reduced salt content in the soil and an increase in dispersion. Table 13 shows an increase in pH values for the soils reacting in this manner, however the air-water permeability ratios tend to dispute this explanation as all the ratio values are lowered by all the treatments.

All soils having a modulus of rupture value over 1300 millibars definitely showed reduced germination, therefore, the crusting tendency as measured by the modulus of rupture plays an important role in germination. This was also found to be true by Richards (63). However, he found that germination was reduced when the value for modulus of rupture was much smaller than the value found in this study. This discrepancy could be explained by the fact that in this study the germination was measured in pots that were watered daily, while his measurements of germination were done in the field. Many other factors could also play a part, such as temperature, type of clay mineral, organic matter content and quality of irrigation water.

That the modulus of rupture is greatly influenced by the quantity of exchangeable sodium in the soil was shown by Brooks et al. (13), and it is therefore difficult to prove from this data whether reduced germination is due to the physical properties of the soil or to the toxic effect of the sodium ion. The data, while limited, indicate that the physical characteristics of the soil (crusting tendency in this case) play a large role in germination. The Wardlow B_{sa} sample, which has an exchangeable sodium percentage of 21.4 but a modulus of rupture value of 723 millibars, promoted 100 per cent germination. The low modulus of rupture is probably due to the high salt content as the electrical conductivity is 11.4 mmhos/cm. which in itself could in

some cases inhibit germination. It should be remembered that these samples were from the B horizon, and that germination usually takes place in the A horizon. Therefore, the depth of A horizon is a major factor in germination in solonetzic soils.

The beneficial effect of gypsum treatments on final yields appears to be significant in the case of the Halladay, Hemaruka, Wardlow B_{sa}, Daugh, Halkirk and Wetaskiwin samples. After the reduction in yield due to reduced germination has been corrected for, only the Hemaruka, Wardlow B_{sa}, Halkirk and Wetaskiwin soils show an increase in productive capacity after the gypsum treatments. Apparently the plants grown on the Halladay and Daugh soils were affected by germination alone. The increases in yield due to gypsum treatment found in this experiment are not in agreement with Gardner's work (27). The visual effect of gypsum treatments on plant growth is shown for four soils in Plate I.

The four soils showing increased adjusted yields all had an initial exchangeable sodium percentage of 20 or more and very high air-water permeability ratios. The exception is the Wardlow B_{sa} where plant growth was likely reduced by a high content of soluble salts. The increased productivity resulting from the addition of gypsum to the Hemaruka, Halkirk and Wetaskiwin soils indicate that gypsum may be effective in the improvement of soil-plant relationships in a number of ways. There could be a decrease in the toxic effect of the sodium ion, an improvement in soil structure for root penetration and aeration, an increase in the availability of calcium for plant food, or some combination of these factors.

The data indicate that gypsum is effective in improving

soil-plant relationships in disturbed soil samples. Two factors are important in this respect: that of reduced germination due to the crusting tendency of high sodium soil, and that of reduced growth after germination which could be due to a number of factors.

PLATE I.

THE EFFECT OF GYPSUM TREATMENTS ON PLANT GROWTH

A.



Daugh B₂ horizon.

B.



Wetaskiwin B₂ horizon.

PLATE I.
(cont.)

THE EFFECT OF GYPSUM TREATMENTS ON PLANT GROWTH

C.



Hemaruka B₂ horizon.

D.



Halkirk B₂ horizon.

SUMMARY

1. The use of gypsum in the reclamation of solonetzic soils was studied in considerable detail.
2. The gypsum treatments increased the quantities of Na^+ , K^+ , Mg^{++} , Ca^{++} and $\text{SO}_4^{=}$ in the leachates but had virtually no effect on the removal of Cl^- . As the rates of gypsum increased the amount of HCO_3^- found in the leachate decreased, this is attributed to the formation of CaCO_3 .
3. The higher applications of gypsum resulted in a substantial lowering of the exchangeable sodium percentage of the soil. The exchangeable magnesium and potassium contents of the soil were slightly lowered and the amount of exchangeable calcium was increased considerably.
4. After the application of 8 tons of gypsum per acre the exchangeable sodium percentage of the Hemaruka, Halkirk and Wetaskiwin soils was still 11.5, 15.4 and 23.1 respectively.
5. The pH of the saturated extracts of the soils was lowered by about 1/10 of one pH unit with the highest application of gypsum.
6. The sodium adsorption ratio (SAR) was found to be a significantly reliable index of the exchangeable sodium percentage (ESP). The following equation was established for deriving ESP values from the SAR.

$$\text{ESP} = \frac{100 (0.016 \text{ SAR} - 0.026)}{1 + (0.016 \text{ SAR} - 0.026)}$$

7. The application of 8 tons of gypsum per acre lowered the air-water permeability ratio to acceptable values in all cases except for the Wetaskiwin soil which had an ESP of 37.3.

8. Gypsum was effective in increasing the disturbed hydraulic conductivity of all the soils except for the Wetaskiwin sample, the hydraulic conductivity of which was not measureable initially.
9. The moisture equivalent was reduced several per cent with the application of gypsum.
10. The gypsum treatments lowered the crusting tendency of the soil provided the application was sufficiently high.
11. In several cases the application of tap water or low concentrations of gypsum solution resulted in the physical condition of the soil becoming more adverse.
12. The work on threshold concentration indicates that it should be possible to maintain permeability during reclamation irrespective of the exchangeable sodium content of the soil by using solutions of electrolytes of sufficient concentrations. The limiting factor for the use of gypsum is its limited solubility in the field.
13. Limited data indicate that the B_{sa} horizons underlying the B_2 or B_3 of solodized solonetz soils contain gypsum in sufficient quantity with sufficient solubility to maintain permeability during the leaching operation.
14. The gypsum requirement measurement appears to be a fairly reliable index for rate of application of gypsum.
15. Germination was reduced considerably when the modulus of rupture exceeded 1300 millibars per cm. This suggests that the depth to the B_2 horizon of the solonetzic soils is of considerable importance in their evaluation as farm land.
16. These data indicate that gypsum is effective in improving soil-

plant relationships. Two factors are important in this respect: that of reduced germination due to the crusting tendency of high sodium soils, and that of reduced growth after germination which could be due to a number of factors.

17. The data obtained in this study indicates that gypsum is effective as an amendment for the reclamation of solonetzic soils provided that the exchangeable sodium does not exceed 20 - 25 per cent of the total exchange capacity and the solubility of gypsum in the field is about one half that of its saturated concentration.

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